Chronology

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1781/82		Nature [1782/3]
1784		On Granite [1877]
1784/85		A Study Based on Spinoza [1891]
1784–1786		An Intermaxillary Bone Is Present in the Upper Jaw of Man As Well As in Animals [1820]
1789		Suggestions for a Comparative Approach Reconciling the Plutonists and Neptunists on the Question of the Origin of Basalt [1892]
1790		*The Metamorphosis of Plants* [1790]
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1791–1807		*Theory of Color: Didactic Section* [1807/8]—Note: the entire *Theory of Color* was published in 1810.
1792		The Experiment As Mediator between Object and Subject [1823]
1794		Fortunate Encounter [1817]
		The Extent to Which the Idea "Beauty Is Perfection in Combination with Freedom" May Be Applied to Living Organisms [1953]
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Nature[1]
[A Fragment by Georg Christoph Tobler]

Nature! We are surrounded and embraced by her—powerless to leave her and powerless to enter her more deeply. Unasked and without warning she sweeps us away in the round of her dance and dances on until we fall exhausted from her arms.

She brings forth ever new forms: what is there, never was; what was, never will return. All is new, and yet forever old.

We live within her, and are strangers to her. She speaks perpetually with us, and does not betray her secret. We work on her constantly, and yet have no power over her.

All her effort seems bent toward individuality, and she cares nothing for individuals. She builds always, destroys always, and her workshop is beyond our reach.

She lives in countless children, and the mother—where is she? She is the sole artist, creating extreme contrast out of the simplest material, the greatest perfection seemingly without effort, the most definite clarity always veiled with a touch of softness. Each of her works has its own being, each of her phenomena its separate idea, and yet all create a single whole.

She plays out a drama: we know not whether she herself sees it, and yet she plays it for us, we who stand in the corner.

There is everlasting life, growth, and movement in her and yet she does not stir from her place. She transforms herself constantly and there is never a moment's pause in her. She has no name for respite, and she has set her curse upon inactivity. She is firm. Her tread is measured, her exceptions rare, her laws immutable.

She thought and she thinks still, not as man, but as nature. She keeps to herself her own all-embracing thoughts which none may discover from her.

All men are in her and she in all. With all she plays a friendly game, and is glad as our winnings grow. With many she plays a hidden game which is ended before they know it.

Even what is most unnatural is nature. The one who does not see her everywhere sees her nowhere clearly.

She loves herself, she adores herself eternally with countless eyes and hearts. She has scattered herself to enjoy herself. She brings forth ever new enjoyers, insatiable in her need to share herself.

She delights in illusion. Whoever destroys this in himself and others she punishes as the sternest tyrant. Whoever follows her trustingly she takes to her heart like a child.

Her children are without number. From none does she withhold all gifts, but upon her favorites she lavishes much and for them she sacrifices much. She has lent her protection to greatness.

Her creatures are flung up out of nothingness with no hint of where they come from or where they are going—they are only to run; she knows the course.

She has few mainsprings to drive her, but these never wind down; they are always at work, always varied.

Her drama is ever new because she creates ever new spectators. Life is her most beautiful invention and death her scheme for having much life.

She wraps man in shadow and forever spurs him to find the light. She makes him a creature dependent upon the earth, sluggish and heavy, and then again and again she shakes him awake.

She gives us needs because she loves movement. A miracle, how little she uses to achieve all this movement. Every need is a favor. Soon satisfied, soon roused again. When she gives us another it is a source of new pleasure. But soon she comes into balance.

At every moment she prepares for the longest race and at every moment she is done with it.

She is vanity itself, but not our vanity. For us she has given herself paramount importance.

She lets every child practice his arts on her, every fool judge her; she allows thousands to pass over her dully, without seeing her. In all this she takes joy and from it she draws her profit.

We obey her laws even in resisting them; we work with her even in working against her.

All she gives she makes a blessing, for she begins by making it a need. She delays so that we long for her; she hurries so that we never have our fill of her.

She has neither language nor speech, but she makes tongues and hearts with which to feel and speak.

Her crown is love. Only through love do we come to her. She opens chasms between all beings, and each seeks to devour the other. She has set all apart to draw all together. With a few draughts from the cup of love she makes good a life full of toil.

She is all. She rewards herself and punishes herself, delights and torments herself. She is rough and gentle, charming and terrifying, im-

potent and all-powerful. All is eternally present in her. She knows nothing of past and future. The present is eternity for her. She is kind. I praise her with all her works. She is wise and still. We may force no explanation from her, wrest no gift from her, if she does not give it freely. She is full of tricks, but to a good end, and it is best not to take note of her ruses.

She is whole and yet always unfinished. As she does now she may do forever.

To each she appears in a unique form. She hides amid a thousand names and terms, and is always the same.

She has brought me here, she will lead me away. I trust myself to her. She may do as she will with me. She will not hate her work. It is not I who has spoken of her. No, what is true and what is false, all this she has spoken. Hers is the blame, hers the glory.

A Commentary on the Aphoristic Essay "Nature" (Goethe to Chancellor von Müller)[1]

This essay recently came to me from the estate of the late, revered Duchess Anna Amalia.[2] It is in a familiar hand,[3] one I often employed in my affairs during the eighties.

I cannot, in fact, remember having composed these remarks, but they reflect accurately the ideas to which my understanding had then attained. I could call the level of my insight at the time a "comparative" which strove to express its development toward a "superlative" not yet reached. The tendency toward a form of pantheism is apparent in the thought that what meets us in the world springs from an unfathomable, limitless, humorous, self-contradictory being. It may be considered a game in deadly earnest.

The missing capstone is the perception of the two great driving forces in all nature: the concepts of *polarity* and *intensification*, the former a property of matter insofar as we think of it as material, the latter insofar as we think of it as spiritual. Polarity is a state of constant attraction and repulsion, while intensification is a state of ever-striving ascent. Since, however, matter can never exist and act without spirit, nor spirit without matter, matter is also capable of undergoing intensification, and spirit cannot be denied its attraction and repulsion. Similarly, the capacity to think is given only to someone who has made sufficient divisions to bring about a union, and who has united sufficiently to seek further divisions.

During the years in which this essay probably falls I was largely occupied with comparative anatomy. In 1786 I was at enormous pains to arouse support for my conviction that *the existence of the intermaxillary bone in man may not be denied*. Even good minds would not admit the importance of this assertion; the best observers denied its validity. As in so many other things, I was forced to go my own way quietly and alone.

I continued to apply myself to the study of nature's versatility in the plant kingdom, and while visiting Sicily in 1787[4] I succeeded in grasping the metamorphosis of plants both perceptually and conceptually. Met-

amorphosis in the animal kingdom is closely related, and in 1790 it became clear to me in Venice that the skull originates from the vertebrae.[5] I then pursued the construction of the prototype with more vigor, dictated my schematic outline to Max Jacobi[6] in 1795 in Jena, and soon had the pleasure of seeing other German researchers continue my work in this area.

If we recall the sublime way in which all natural phenomena have been linked bit by bit in human thought, and if we then take a second look at the above essay as our point of departure, we cannot but smile *when we contrast that "comparative" (as I termed it) to the* "superlative" which forms our end point—thus we will find pleasure in fifty years of progress.

Weimar
May 24, 1828

A Study Based on Spinoza[1]

The concepts of being and totality are one and the same; when pursuing the concept as far as possible, we say that we are conceiving of the infinite.

But we cannot think of the infinite, or of total existence.

We can conceive only of things which are finite or made finite by our mind; i.e., the infinite is conceivable only insofar as we can imagine total existence—but this task lies beyond the power of the finite mind.

The infinite cannot be said to have parts.

Although all finite beings exist within the infinite, they are not parts of the infinite; instead, they partake of the infinite.

We have difficulty believing that something finite might exist through its own nature. Yet everything actually exists through its own nature, although conditions of existence are so linked together that one condition must develop from the other. Thus it seems that one thing is produced by another, but this is not so—instead, one living being gives another cause to be, and compels it to exist in a certain state.

Therefore being is within everything that exists, and thus also the principle of conformity which guides its existence.

The process of measuring is a coarse one, and extremely imperfect when applied to a living object.

A living thing cannot be measured by something external to itself; if it must be measured, it must provide its own gauge. This gauge, however, is highly spiritual, and cannot be found through the senses. Even in the circle the gauge of the diameter may not be applied to the periphery. There have been attempts to measure the human being mechanically: painters have chosen the head as the best portion to use for a unit of measurement. But this cannot be done without creating tiny, indefinable distortions in the other parts of the body.

The things we call the parts in every living being are so inseparable from the whole that they may be understood only in and with the whole.

As we stated above, a finite living being partakes of infinity, or rather, it has something infinite within itself. We might better say: in a finite living being the concepts of existence and totality elude our understanding; therefore we must say that it is infinite, just as we say that the vast whole containing all beings is infinite.

The things which enter our consciousness are vast in number, and their relations—to the extent the mind can grasp them—are extraordinarily complex. Minds with the inner power to grow will begin to establish an order so that knowledge becomes easier; they will begin to satisfy themselves by finding coherence and connection.

Thus all of existence and totality must be made finite in our minds so that it conforms to our nature and our way of thinking and feeling. Only then will we say that we understand something, or enjoy it.

The mind may perceive the seed, so to speak, of a relation which would have a harmony beyond the mind's power to comprehend or experience once the relation is fully developed. When this happens, we call the impression sublime; it is the most wonderful bestowed on the mind of man.

When we find a relation our mind is almost able to follow or grasp as it unfolds, we call the impression great.

We said above that all living things in existence have their relation within themselves; thus we call the individual or collective impression they make on us true—so long as it springs from the totality of their existence. We call the object beautiful when this existence is partially finite so that we grasp it easily, when it is related to our nature so that we grasp it with pleasure.

A similar thing may occur when a person (within the limits of his ability) has formed a whole—be it extensive or scanty—from the relationship of things, when he has finally closed the circle. He then believes that what is most comfortable to think, what brings pleasure, is also what is most sure and certain. Indeed, we often find him gazing with self-satisfied pity on those less easily contented, those who strive to discover and understand further relationships between things divine and human. At every opportunity he lets us know with self-deprecating arrogance: in the realm of truth he has found a certainty exalted beyond any need for proof and understanding. He cannot do enough in proclaiming the enviable peace and joy he feels, and in calling attention to this bliss as the ultimate goal for all. But because he can show neither how he arrived at this conviction nor what its real basis is, he offers little comfort to those seeking instruction. Instead, they will hear repeatedly that their minds must grow ever simpler, that they must focus on one point alone and dismiss all thought of complex and confusing relationships. Only then—but all the more certainly—

will they find happiness in a state given freely by God as a gift and special boon.

Indeed, to our way of thinking this limitation is no boon, for a defect cannot be viewed as a boon. But we might see a blessing of nature in the fact that man, who is usually able to achieve only partial concepts, may nonetheless find such satisfaction in his narrowness.

The Experiment As Mediator between Object and Subject

As the human being becomes aware of objects in his environment he will relate them to himself, and rightly so since his fate hinges on whether these objects please or displease him, attract or repel him, help or harm him. This natural way of seeing and judging things seems as easy as it is essential, although it can lead to a thousand errors—often the source of humiliation and bitterness in our life.

A far more difficult task arises when a person's thirst for knowledge kindles in him a desire to view nature's objects in their own right and in relation to one another. On the one hand he loses the yardstick which came to his aid when he looked at things from the human standpoint; i.e., in relation to himself. This yardstick of pleasure and displeasure, attraction and repulsion, help and harm, he must now renounce absolutely; as a neutral, seemingly godlike being he must seek out and examine what is, not what pleases. Thus the true botanist must remain unmoved by beauty or utility in a plant; he must explore its formation, its relation to other plants. Like the sun which draws forth every plant and shines on all, he must look upon each plant with the same quiet gaze; he must find the measure for what he learns, the data for judgment, not in himself but in the sphere of what he observes.

The history of science teaches us how difficult this renunciation is for man. The second part of our short essay will discuss how he thus arrives (and must arrive) at hypotheses, theories, systems, any of the modes of perception which help in our effort to grasp the infinite; the first part of the essay will deal with how man sets about recognizing the forces of nature. Recently I have been studying the history of physics[1] and this point arose frequently—hence the present brief discourse, an attempt to outline in general how the study of nature has been helped or hindered by the work of able scientists.

We may look at an object in its own context and the context of other objects, while refraining from any immediate response of desire or dislike. The calm exercise of our powers of attention will quickly lead us to a rather clear concept of the object, its parts, and its relationships;

the more we pursue this study, discovering further relations among things, the more we will exercise our innate gift of observation. Those who understand how to apply this knowledge to their own affairs in a practical way are rightly deemed clever. It is not hard for any well-organized person, moderate by nature or force of circumstance, to be clever, for life corrects us at every step. But if the observer is called upon to apply this keen power of judgment to exploring the hidden relationships in nature, if he is to find his own way in a world where he is seemingly alone, if he is to avoid hasty conclusions and keep a steady eye on the goal while noting every helpful or harmful circumstance along the way, if he must be his own sharpest critic where no one else can test his work with ease, if he must question himself continually even when most enthusiastic—it is easy to see how harsh these demands are and how little hope there is of seeing them fully satisfied in ourselves or others. Yet these difficulties, this hypothetical impossibility, must not deter us from doing what we can. At any rate, our best approach is to recall how able men have advanced the sciences, and to be candid about the false paths down which they have strayed,[2] only to be followed by numerous disciples, often for centuries, until later empirical evidence could bring researchers back to the right road.

It is undeniable that in the science now under discussion, as in every human enterprise, empirical evidence carries (and should carry) the greatest weight. Neither can we deny the high and seemingly creative independent power found in the inner faculties through which the evidence is grasped, collected, ordered, and developed. But how to gather and use empirical evidence, how to develop and apply our powers—this is not so generally recognized or appreciated.

We might well be surprised how many people are capable of sharp observation in the strictest sense of the word. When we draw their attention to objects, we will discover that such people enjoy making observations, and show great skill at it. Since taking up my study of light and color I have often had opportunity to appreciate this. Now and then I discuss my current interests with people unacquainted with the subject: once their attention is awakened they frequently make quick note of phenomena I was unaware of or had neglected to observe. Thus they may be able to correct ideas developed in haste, and even produce a breakthrough by transcending the inhibitions in which exacting research often traps us.

Thus what applies in so many other human enterprises is also true here: the interest of many focused on a single point can produce excellent results. Here it becomes obvious that the researcher will meet his downfall if he has any feeling of envy which seeks to deprive others of the discoverer's laurels, any overwhelming desire to deal alone and arbitrarily with a discovery.

I have always found the cooperative method of working satisfactory, and I intend to continue with it. I am aware of the debts I have incurred along the way, and it will give me great pleasure later to acknowledge these publicly.

If man's natural talent for observation can be of such help to us, how much more effective must it be when trained observers work hand in hand. In and of itself, a science is sufficient to support the work of many people, although no one person can carry an entire science. We may note that knowledge, like contained but living water, rises gradually to a certain level, and that the greatest discoveries are made not so much by men as by the age; important advances are often made by two or more skilled thinkers at the same time. We have already found that we owe much to the community and our friends; now we discover our debt to the world and the age we live in. In neither case can we appreciate fully enough our need for communication, assistance, admonition, and contradiction to hold us to the right path and help us along it.

Thus in scientific matters we must do the reverse of what is done in art. An artist should never present a work to the public before it is finished because it is difficult for others to advise or help him with its production. Once it is finished, however, he must consider criticism or praise, take it to heart, make it a part of his own experience, and thereby develop and prepare himself for new works. In science, on the other hand, it is useful to publish every bit of empirical evidence, even every conjecture; indeed, no scientific edifice should be built until the plan and materials of its structure have been widely known, judged and sifted.

I will now turn to a point deserving of attention; namely, the method which enables us to work most effectively and surely.

When we intentionally reproduce empirical evidence found by earlier researchers, contemporaries, or ourselves, when we re-create natural or artificial phenomena, we speak of this as an experiment.

The main value of an experiment lies in the fact that, simple or compound, it can be reproduced at any time given the requisite preparations, apparatus, and skill. After assembling the necessary materials we may perform the experiment as often as we wish. We will rightly marvel at human ingenuity when we consider even briefly the variety of arrangements and instruments invented for this purpose. In fact, we can note that such instruments are still being invented daily.

As worthwhile as each individual experiment may be, it receives its real value only when united or combined with other experiments. However, to unite or combine just two somewhat similar experiments calls for more rigor and care than even the sharpest observer usually expects of himself. Two phenomena may be related, but not nearly so

closely as we think. Although one experiment seems to follow from another, an extensive series of experiments might be required to put the two into an order actually conforming to nature.

Thus we can never be too careful in our efforts to avoid drawing hasty conclusions from experiments or using them directly as proof to bear out some theory. For here at this pass, this transition from empirical evidence to judgment, cognition to application, all the inner enemies of man lie in wait: imagination, which sweeps him away on its wings before he knows his feet have left the ground; impatience; haste; self-satisfaction; rigidity; formalistic thought; prejudice; ease; frivolity; fickleness—this whole throng and its retinue. Here they lie in ambush and surprise not only the active observer but also the contemplative one who appears safe from all passion.

I will present a paradox of sorts as a way of alerting the reader to this danger, far greater and closer at hand than we might think. I would venture to say that we cannot prove anything by one experiment or even several experiments together, that nothing is more dangerous than the desire to prove some thesis directly through experiments, that the greatest errors have arisen just where the dangers and shortcomings in this method have been overlooked. I will explain this assertion more clearly lest I merely seem intent on raising a host of doubts. Every piece of empirical evidence we find, every experiment in which this evidence is repeated, really represents just one part of what we know. Through frequent repetition we attain certainty about this isolated piece of knowledge. We may be aware of two pieces of empirical evidence in the same area; although closely related, they may seem even more so, for we will tend to view them as more connected than they really are. This is an inherent part of man's nature; the history of human understanding offers thousands of examples of this, and I myself make this error almost daily.

This mistake is associated with another which often lies at its root. Man takes more pleasure in the idea than in the thing; or rather, man takes pleasure in a thing only insofar as he has an idea of it. The thing must fit his character, and no matter how exalted his way of thinking, no matter how refined, it often remains just a way of thinking, an attempt to bring several objects into an intelligible relationship which, strictly speaking, they do not have. Thus the tendency to hypotheses, theories, terminologies, and systems, a tendency altogether understandable since it springs by necessity from the organization of our being.

Every piece of empirical evidence, every experiment, must be viewed as isolated, yet the human faculty of thought forcibly strives to unite all external objects known to it. It is easy to see the risk we run when we try to connect a single bit of evidence with an idea already formed, or use individual experiments to prove some relationship not fully per-

ceptible to the senses but expressed through the creative power of the mind.

Such efforts generally give rise to theories and systems which are a tribute to their author's intelligence. But with undue applause or protracted support they soon begin to hinder and harm the very progress of the human mind they had earlier assisted.

We often find that the more limited the data, the more artful a gifted thinker will become.[3] As though to assert his sovereignty he chooses a few agreeable favorites from the limited number of facts and skillfully marshals the rest so they never contradict him directly. Finally he is able to confuse, entangle, or push aside the opposing facts and reduce the whole to something more like the court of a despot than a freely constituted republic.

So deserving a man will not lack admirers and disciples who study this fabric of thought[4] historically, praise it, and seek to think as much like their master as possible. Often such a doctrine becomes so widespread that anyone bold enough to doubt it would be considered brash and impertinent. Only in later centuries would anyone venture to approach such a holy relic, apply common sense to the subject, and—taking a lighter view—apply to the founder of the sect what a wag once said of a renowned scientist: "He would have been a great man if only he hadn't invented so much."

It is not enough to note this danger and warn against it. We need to declare our own views by showing how we ourselves would hope to avoid this pitfall, or by telling what we know of how some predecessor avoided it.

Earlier I stated my belief that the direct use of an experiment to prove some hypothesis is detrimental; this implies that I consider its indirect use beneficial. Here we have a pivotal point, one requiring clarification.

Nothing happens in living nature that does not bear some relation to the whole. The empirical evidence may seem quite isolated, we may view our experiments as mere isolated facts, but this is not to say that they are, in fact, isolated. The question is: how can we find the connection between these phenomena, these events?

Earlier we found those thinkers most prone to error who seek to incorporate an isolated fact directly into their thinking and judgment. By contrast, we will find that the greatest accomplishments come from those who never tire in exploring and working out every possible aspect and modification of every bit of empirical evidence, every experiment.

It would require a second essay to describe how our intellect can help us with this task; here we will merely indicate the following. All things in nature, especially the commoner forces and elements, work incessantly upon one another; we can say that each phenomenon is

connected with countless others just as we can say that a point of light floating in space sends its rays in all directions. Thus when we have done an experiment of this type, found this or that piece of empirical evidence, we can never be careful enough in studying what lies next to it or derives directly from it. This investigation should concern us more than the discovery of what is related to it. To follow every single experiment through its variations is the real task of the scientific researcher. His duty is precisely the opposite of what we expect from the author who writes to entertain. The latter will bore his readers if he does not leave something to the imagination, while the former must always work as if he wished to leave nothing for his successors to do. Of course, the disproportion between our intellect and the nature of things will soon remind us that no one has gifts enough to exhaust the study of any subject.

In the first two parts of my *Contributions to Optics*[5] I sought to set up a series of contiguous experiments derived from one another in this way. Studied thoroughly and understood as a whole, these experiments could even be thought of as representing a single experiment, a single piece of empirical evidence explored in its most manifold variations.

Such a piece of empirical evidence, composed of many others, is clearly of a higher sort. It shows the general formula, so to speak, that overarches an array of individual arithmetic sums. In my view, it is the task of the scientific researcher to work toward empirical evidence of this higher sort—and the example of the best men in the field supports this view. From the mathematician we must learn the meticulous care required to connect things in unbroken succession, or rather, to derive things step by step. Even where we do not venture to apply mathematics we must always work as though we had to satisfy the strictest of geometricians.

In the mathematical method we find an approach which by its deliberate and pure nature instantly exposes every leap in an assertion. Actually, its proofs merely state in a detailed way that what is presented as connected was already there in each of the parts and as a consecutive whole, that it has been reviewed in its entirety and found to be correct and irrefutable under all circumstances. Thus its demonstrations are always more exposition, recapitulation, than argument. Having made this distinction, I may now return to something mentioned earlier.

We can see the great difference between a mathematical demonstration which traces the basic elements through their many points of connection, and the proof offered in the arguments of a clever speaker. Although arguments may deal with utterly separate matters, wit and imagination can group them around a single point to create a surprising semblance of right and wrong, true and false. It is likewise possible to support a hypothesis or theory by arranging individual experiments like arguments and offering proofs which bedazzle us to some degree.

But those who wish to be honest with themselves and others will try by careful development of individual experiments to evolve empirical evidence of the higher sort. These pieces of evidence may be expressed in concise axioms and set side by side, and as more of them emerge they may be ordered and related. Like mathematical axioms they will remain unshakable either singly or as a whole. Anyone may examine and test the elements, the many individual experiments, which constitute this higher sort of evidence; it will be easy to judge whether we can express these many components in a general axiom, for nothing here is arbitrary.

The other method which tries to prove assertions by using isolated experiments like arguments often reaches its conclusions furtively or leaves them completely in doubt. Once sequential evidence of the higher sort is assembled, however, our intellect, imagination and wit can work upon it as they will; no harm will be done, and, indeed, a useful purpose will be served. We cannot exercise enough care, diligence, strictness, even pedantry, in collecting basic empirical evidence; here we labor for the world and the future. But these materials must be ordered and shown in sequence, not arranged in some hypothetical way nor made to serve the dictates of some system. Everyone will then be free to connect them in his own way, to form them into a whole which brings some measure of delight and comfort to the human mind. This approach keeps separate what must be kept separate; it enables us to increase the body of evidence much more quickly and cleanly than the method which forces us to cast aside later experiments like bricks brought to a finished building.

The views and examples of the best men give me reason to hope that this is the right path, and I trust my explanation will satisfy those of my friends who ask from time to time what I am really seeking to accomplish with my optical experiments. My intention is to collect all the empirical evidence in this area, do every experiment myself, and develop the experiments in their most manifold variations so that they become easy to reproduce and more accessible. I will then attempt to establish the axioms in which the empirical evidence of a higher nature can be expressed, and see if these can be subsumed under still higher principles. If imagination and wit sometimes run impatiently ahead on this path, the method itself will fix the bounds to which they must return.

April 28, 1792

Fortunate Encounter[1]

I enjoyed the most wonderful moments of my life during my research on the metamorphosis of plants, a time when I arrived at a clear perception of the sequence in their progression. This perception filled me with enthusiasm during my stay in Naples and Sicily.[2] More and more I came to appreciate this way of looking at the plant kingdom, and while traveling highway and byway I had constant opportunity to exercise it. But these pleasant labors were destined to grow enormously in value when they led to one of the deepest relationships fortune brought me in my later years. It is to these pleasurable experiences that I owe my closer connection with Schiller, for they cleared away the misunderstandings which had long held me apart from him.

In Italy I had sought to acquire greater precision and clarity in all areas of the arts; at the time I paid no heed to what was happening in Germany. Upon my return from Italy[3] I discovered that certain works of current and older literature had become popular and widely influential. Unfortunately these were works which repelled me strongly: here I will cite only Heinse's *Ardinghello* and *The Robbers* by Schiller.[4] I found the former author offensive because he attempted through the fine arts to ennoble and defend sensuality and an abstruse way of thinking. The latter offended me because his powerful but immature talent had poured out over our homeland a completely overwhelming flood of ethical and theatrical paradoxes, the very paradoxes from which I had been attempting to free myself.

I found fault with neither of these talented men in regard to their enterprise and accomplishment, for no one can deny in himself the desire to work in his own way. He first tries to do so unconsciously and out of ignorance, then with increasing consciousness at each step of his growth in knowledge. This is why there is so much excellence and so much foolishness spread throughout the world, and confusion follows upon confusion.

But the uproar this created in my homeland, the applause accorded these strange monstrosities by everyone from wild students to the cul-

tivated lady of the court—these things alarmed me, for I thought I was seeing all my own efforts being reduced to naught. It seemed that the subjects of my study and my whole way of acquiring knowledge were being cast aside and crippled. Most painful of all was that my close friends Heinrich Meyer and Moritz, as well as Tischbein and Bury[5] (two artists who shared my views), also appeared to be dangerously affected by this. I was quite disconcerted. I would gladly have abandoned my study of the fine arts and poetic work had this been possible. Where was the least hope of stemming this tide, imbued with genius and wild in form? You can imagine the state I was in! I had striven to encourage and disseminate the clearest of perceptions, and now I found myself hemmed in between Ardinghello and Franz Moor.[6]

Moritz, also back from Italy and my guest for a time, supported me strongly in this opinion. I avoided Schiller although he was in Weimar and lived close by.[7] The publication of *Don Carlos*[8] was not designed to bring me any closer to him; I rejected all attempts at this by mutual friends, and thus for a time we lived side by side as strangers.

His essay "On Grace and Dignity" likewise offered me no point of reconciliation. He had joyfully assimilated the philosophy of Kant which so exalts the subjective element although it appears to put limits on it. This philosophy stimulated the development of the extraordinary qualities with which Nature had endowed him, and in an ecstasy of freedom and self-determination he lost all sense of gratitude toward the great Mother who had not at all treated him like a stepson. He did not view her as she is, a source of creation from the deepest depths to the loftiest heights, going about her living work in accord with systematic laws; instead, he chose as his focus a few empirical qualities of human nature. I could even interpret several harsh passages as aimed right at me; these cast my beliefs in a false light. At the same time I felt it would be even worse if I were not their target, for the vast abyss between our different ways of thought would then gape all the wider.

An accord was inconceivable. Even the gentle promptings of a Dalberg,[9] with his grasp of Schiller's talents, remained of no avail. It was, in fact, difficult to argue with the reasons I advanced for refusing any accord. No one can deny that more than an Earth's diameter lies between two antipodes of the spirit: each would wish to maintain its own identity as a pole, and hence it is impossible for them to merge. Yet a relationship still exists between them, as the following will make clear.

Schiller moved to Jena,[10] but I did not see him there either. Batsch,[11] with enormous energy, had in the meantime founded a society for scientific research, equipped with a wonderful collection of materials and substantial resources. I often attended its periodic meetings. At one such meeting[12] I found Schiller also in attendance. We happened to leave the meeting at the same time, and a conversation ensued. He

seemed interested in the presentation, but commented intelligently and perceptively that such a fragmented way of dealing with nature could hardly appeal to any layman who wished to pursue the topic. I welcomed his remarks.

I replied that this method would probably disconcert even the initiated, and that a different approach might well be discovered, not by concentrating on separate and isolated elements of nature but by portraying it as alive and active, with its efforts directed from the whole to the parts. He asked me to explain this point further, but was unable to hide his doubts. He could not agree that what I described might be derived directly from empirical observation.

We reached his house, and our conversation drew me in. There I gave an enthusiastic description of the metamorphosis of plants, and with a few characteristic strokes of the pen I caused a symbolic plant[13] to spring up before his eyes. He heard and saw all this with great interest, with unmistakable power of comprehension. But when I stopped, he shook his head and said, "That is not an observation from experience. That is an idea." Taken aback and somewhat annoyed, I paused; with this comment he had touched on the very point that divided us. It evoked memories of the views he had expressed in "On Grace and Dignity"; my old resentment began to rise in me. I collected my wits, however, and replied, "Then I may rejoice that I have ideas without knowing it, and can even see them with my own eyes."

Schiller possessed much more *savoir vivre* and tact than I, and because of the *Horen*[14] (which he had just begun to edit) he was also more intent on winning me over than on repelling me. He answered as a cultivated Kantian, and when my stubborn realism touched off a lively rejoinder we embarked on a long struggle, then arrived at a truce. Neither of us could claim victory; each was convinced his position was impregnable. Statements like the following made me quite unhappy: "How can we ever have an experience which conforms with an idea? An experience can never be congruent with an idea—that is precisely what makes the idea unique." If he viewed what I called experience as an idea, surely some mediating element, some connecting element, must lie between the two! Nonetheless, the first step had been taken. Schiller had great magnetism; everyone who approached him was captivated. I agreed with his plans, and for the *Horen* I promised to part with several things I had in reserve. His wife,[15] whom I had loved and admired from the time she was a child, made her own contribution to our lasting relationship. All our mutual friends were overjoyed, and thus through the most intense conflict between object and subject, perhaps never fully to be resolved, we sealed an enduring union rich in benefit to us and to others.

This happy beginning and the decade of friendship that followed[16]

led to the gradual development of my aptitude for philosophy (insofar as such an aptitude lay in my nature). I intend to give the fullest possible account of this development, although the difficulties in doing so will immediately be apparent to the experienced observer. From a higher standpoint we may be able to see the easy confidence of man's intellect, the intellect given a healthy human being by birth and never prone to uncertainties about things and their relationships or about its own ability to know, to grasp, to judge, to appreciate, to use these things. Those sharing this higher point of view will doubtless agree that an almost impossible task confronts anyone seeking to depict the phases, thousands in number, leading to a purer, freer state of self-awareness. Here there can be no talk of stages in development, only of wrong turns, twisting roads, hidden ways, and finally of the unintended jump, the energetic leap which takes us to a higher level of understanding.

And, after all, in regard to knowledge who can claim that he always traverses the highest reaches of consciousness, there to observe the external world in the most meticulous detail, with an attentiveness as sharp as it is calm, and there also to give rein to his own inner life with sensible discretion, with modest caution—all in the patient hope of acquiring a truly pure and harmonious perceptive vision? Does the world not cast a cloud over such moments, do we ourselves not do so? Yet we may continue in our devout hopes; nothing forbids us to seek a loving approach to what lies beyond our reach.

Where our description succeeds, we would commend it to long-respected friends and also to the young people of Germany who are searching for what is just and right.

It is our wish that from the latter we might draw fresh allies and win over future advocates.

The Extent to Which the Idea "Beauty Is Perfection in Combination with Freedom" May Be Applied to Living Organisms[1]

An organic being is so multifaceted in its exterior, so varied and inexhaustible in its interior, that we cannot find enough points of view nor develop in ourselves enough organs of perception to avoid killing it when we analyze it. I will attempt to apply the idea "Beauty is perfection in combination with freedom" to living organisms.

The members of every creature are formed so that it may enjoy its existence, and maintain and propagate itself; in this sense everything alive deserves to be called perfect. Here I will turn immediately to the so-called more perfect animals.

If the members of an animal are so formed that the creature can give expression to its being only in a limited way, we will find the animal ugly; limitation of organic nature to a single purpose will produce a preponderance of one or another of its members, rendering the free use of the remaining members difficult.

When I look at this animal my attention will be drawn to the parts which predominate—the creature cannot make a harmonious impression because it has no harmony. Thus the mole is perfect but ugly because its form permits only a few, limited actions, and the preponderance of certain parts renders him misshapen.

Therefore, if an animal is to satisfy even its most limited basic needs without difficulty, it must be perfectly organized. After satisfying its needs, however, it may have enough strength and power left to initiate voluntary actions which are somewhat without purpose; in this case its exterior will also yield an impression of beauty.

Thus if I say this animal is beautiful I am unable to prove my assertion by using some proportion of number or measure. Instead I am stating only: in this animal all the members are so related that none hinders the action of another; compulsion and need are entirely hidden from my sight by a perfect balance so that the animal seems free to act and work just as it chooses. We may recall the sight of a horse using its limbs in freedom.

If we now rise to man, we will find that he is at last almost free of

the fetters of animality; his limbs are in a delicate state of subordination and coordination, governed by his will more than those of any other animal, and suited not only to any application but also an expression of the mind. Here I allude to the language of gesture which is restrained in well-bred people, and which, I believe, does as much as the language of words to elevate man above the animal.

To develop the concept of a beautiful human in this manner would require that we take countless matters into consideration; there is clearly much to be done before the exalted concept of freedom can crown human perfection, even in the physical sense.

Here I must note a further point. We call an animal beautiful when it gives the impression that it *could* use its limbs at will, but when it really uses them as it chooses, the idea of the beautiful is immediately lost in feelings of the pretty, the pleasant, the easy, the splendid, etc. Thus we see that beauty actually calls for *repose* together with *strength, inaction* together with *power*.

If the notion of asserting the power of a body or some limb is too closely associated with the being's physical existence, the spirit of the beautiful seems to take flight immediately: the ancients depicted even their lions in the greatest degree of repose and neutrality in order to draw forth the feeling with which we grasp beauty.

I would say that we consider a perfectly organized being beautiful if, in beholding it, we can believe it *capable of manifold and free use of all its members whenever it wishes*. Thus the most intense feeling of beauty is connected with feelings of trust and hope.

It seems to me that an essay on the animal and human form viewed in this way might yield agreeable insights and show some interesting relationships.

In particular, this would elevate the concept of proportion (which we usually try to express through number or measure, as mentioned above) to more spiritual principles, and it is my hope that these spiritual principles might at last come to agree with the approach used by the great artists whose works have come down to us, and also encompass those beautiful products of nature which appear among us from time to time in living form.

Especially interesting would be a discussion of how distinctive features could be generated without going beyond the bounds of beauty, how limitation and specialization could appear without impairing freedom.

To be unique and truly helpful to future friends of nature and art, this treatise would have to be based on anatomy and physiology. However, it is not easy to imagine a form of discourse suitable for the presentation of such a varied and wondrous whole.

Empirical Observation and Science[1]

Phenomena, which others of us may call facts, are certain and definite by nature, but often uncertain and fluctuating in appearance. The scientific researcher strives to grasp and keep the definite aspect of what he beholds; in each individual case he is careful to note not only how the phenomena appear, but also how they should appear. There are many empirical fractions which must be discarded if we are to arrive at a pure, constant phenomenon—as I can frequently note, especially in my present field of study.[2] However, the instant I allow myself this, I already establish a type of ideal.

But there is a great difference between someone like the theorist who turns whole numbers into fractions for the sake of a theory, and someone who sacrifices an empirical fraction for the idea of the pure phenomenon.

For the observer never sees the pure phenomenon with his own eyes; rather, much depends on his mood, the state of his senses, the light, air, weather, the physical object, how it is handled, and a thousand other circumstances. Hence it is like trying to drink the sea dry if we try to stay with the individual aspect of the phenomenon, observe it, measure it, weigh it, and describe it.

In my observation of nature and reflection on it I have attempted to remain true to the following method as much as possible, especially in my recent work.

After observing a certain degree of constancy and consistency in phenomena, I derive an empirical law from my observation and expect to find it in later phenomena. If the law and the phenomena are in complete agreement, I have succeeded; if they are not in complete agreement, my attention is drawn to the circumstances surrounding each case, and I am forced to find new conditions for conducting the contradictory experiments in a purer way. But if a case which contradicts my law arises often and under similar circumstance, I realize that I must go further in my research and seek out a higher standpoint.

In my experience, this is the very point where the human mind can come closest to things in their general state, draw them near, and, so to speak, form an amalgam[3] with them just as it usually does in common empiricism, but now in a rational way.

Thus the results of our work are:

1. *The empirical phenomenon,*
   which everyone finds in nature, and which is then raised through experiments to the level of
2. *the scientific phenomenon*
   by producing it under circumstance and conditions different from those in which it was first observed, and in a sequence which is more or less successful.
3. *The pure phenomenon*
   now stands before us as the result of all our observations and experiments. It can never be isolated, but it appears in a continuous sequence of events. To depict it, the human mind gives definition to the empirically variable, excludes the accidental, sets aside the impure, untangles the complicated, and even discovers the unknown.

This is perhaps the ultimate goal of our efforts, at least if we have the right sense of our own limits. For here it is not a question of causes, but of conditions under which the phenomena appear; their consistent sequence, their eternal return under thousands of circumstances, their uniformity and mutability are perceived and predicted; their defined quality is recognized and again defined by the human mind.

In reality this work could not be called speculative, for it seems to me that in the end these are just the practical and self-distilling processes of common human understanding as it ventures to apply itself to a higher sphere.

Weimar
January 15, 1798

Symbolism

Neither things nor ourselves find full expression in our words.

Something like a new world is created through language, one consisting of the essential and the incidental.

Verba valent sicut numi.[1] But there are different sorts of money: gold, silver, and copper coins, or paper money. The coins are real to a degree; the paper money is only convention.[2]

We get by in life with our everyday language, for we describe only superficial relationships. The instant we speak of deeper relationships, another language springs up: poetic language.

In speaking of nature's inner relationships, we need many modes of description. I will mention four here:

Symbols

1. which are physically and really identical with the object: e.g., we have learned to express magnetic effects, and now apply this terminology to related phenomena;[3]

2. which are esthetically and really identical with the object. All good metaphors belong in this category, but we must guard against a display of wit which seems to relate the unrelated instead of finding true relationships;

3. which express a connection which is somewhat arbitrary rather than fully intrinsic; such a symbol, however, points to an inner relationship between phenomena. I would say these symbols are mnemonics in a higher sense, for ordinary mnemonics uses wholly arbitrary notation;

4. which are derived from mathematics. Because they are founded on intuitive perceptions, they can become identical with the phenomenon in the highest sense of the word.

We find instances of the first three symbols in language:

1. when, for example, the word expresses a sound (like the noun *bang*).

2. when the sound expresses an identical feeling (this often happens in inflected forms: *banging*).

3. when related words have a similar sound (like *mine* and *thine*); such words might be dissimilar (*I* and *thou*), but *moi* and *toi* are related in this way.[4]

The fourth type, based on intuitive perceptions alone, cannot occur in language.

The Influence of Modern Philosophy

I had no sense for philosophy in the real meaning of the word; I had only the continuing response brought by my need to resist the intrusions of the world and take hold of it. This response necessarily led me to a way of seizing upon philosophers' opinions as if they were objects from which something might be learned. As a youth I loved to read in Brucker's history of philosophy,[1] yet I read it like a man whose life is spent looking up at the circling of the stars in heaven, a man who sees the most obvious constellations, but without any understanding of astronomy; one with knowledge of the Big Dipper but not of the North Star.

I had often discussed art and its theoretical requirements with Moritz[2] in Rome; the evidence of our fruitful perplexity can be found even today in one short publication. Moreover, in describing plant metamorphosis I found it necessary to develop a method which conformed to nature. There was no latitude for error as the vegetation revealed its processes to me step by step. Without interfering, I had to recognize the ways and means the plant used as it gradually rose from a state of complete encapsulation to one of perfection. In my physics experiments I became convinced that any observation of physical objects required above all that I be thorough in my search for every condition under which a phenomenon may arise, and that I be as comprehensive as possible in collecting phenomena. In the end, the phenomena must form a series, or rather, overlap; thus they give the scientist a picture of some organization by which the inner life of the phenomena become manifest as a whole. All the while I was only dimly aware of these things; nowhere did I find any enlightenment suited to my nature, for ultimately no man can be enlightened in a way not his own.

Kant's *Critique of Pure Reason*[3] had long since appeared, but it lay entirely beyond my ken. I heard a few discussions of the work, however, and I could see that an old issue was being revived: i.e., what role do we ourselves play in our intellectual life, and what part is played by the external world. I had never separated the two, and when I philo-

sophized about things in my own way I did so with unconscious naiveté; I truly believed that my eyes beheld what my mind thought true. But when this dispute arose I found myself on the side of those who put the human being in the best light. I applauded my friends who said with Kant: although all knowledge may be prompted by experience, it does not therefore follow that it arises wholly from experience. I liked the ideas of knowledge *a priori* and synthetic judgments *a priori*. All my life, whether in poetry or research, I had alternated between a synthetic approach and an analytic one—to me these were the systole and the diastole[4] of the human mind, like a second breathing, never separated, always pulsing. I had no words (much less, concepts) to describe these things; but now, for the first time, theory seemed to smile on me. I found pleasure in the portal but I dared not set foot in the labyrinth itself; sometimes my gift for poetry got in my way, sometimes common sense, and I felt that I made little progress.

Actually, Herder[5] was a student of Kant, but, unfortunately, also his opponent; now I was in an even worse state, for I could not agree with Herder, nor could I follow Kant. In the meantime I was intent on continuing my studies of the formation and transformation of organisms,[6] and here the method I had applied to plants proved to be a reliable guide. I could not help but notice that nature always follows an analytic course—development out of a living, mysterious whole—but then seems to act synthetically in bringing together apparently alien circumstances and joining them into one. Thus I returned again and again to Kant's teachings, thought that I understood a few of the principles, and learned much that was useful.

Then the *Critique of Judgment* fell into my hands, and with this book a wonderful period arrived in my life. Here I found my most disparate interests brought together; products of art and nature were dealt with alike, esthetic and teleological judgment illuminated one another. I did not always agree with the author's way of thinking, and occasionally something seemed to be missing, but the main ideas in the book were completely analogous to my earlier work and thought. The inner life of nature and art, their respective effects as they work from within—all this came to clear expression in the book. The products of these two infinitely vast worlds were shown to exist for their own sake;[7] things found together might be there *for* one another, but not *because* of one another (at least not intentionally).

The antipathy I felt toward ultimate causes was now put in order and justified. I could make a clear distinction between purpose and effect, and I saw why our human understanding so often confuses the two. I was glad to find poetry and comparative science related so closely: both are subject to the same faculty of judgment. Now passionately enthusiastic, I was all the more eager to pursue my own paths

because I had no idea where they led, and because the what and how of my discoveries met with little approval among the Kantians. After all, I was only expressing what had stirred in me, and not what I had read. Thrown back on my own devices, I read the book again and again. I still have my old copy, and turn with pleasure to the sections I marked at the time. I also find marked sections in the *Critique of Reason* which I seem to have understood more deeply than before, for two works sprung from one mind always shed light on one another. I did not have the same success in approaching the Kantians: they listened to me, but were unable to respond or help in any way. It happened several times that one or the other of them would admit with a bemused smile: this is indeed an analogue to Kantian thought, but a peculiar one.

It did not become clear just how extraordinary the situation was until I established my connection with Schiller.[8] Our discussions were quite productive or theoretical, and usually both. He preached the gospel of freedom, while I defended the rights of nature. Perhaps more out of friendship to me than any belief of his own, he described Mother Nature in his esthetic letters without those rough expressions I found so distasteful in his essay "On Grace and Dignity." For my part, I stubbornly insisted on the superiority of Greek poetry (or poetry based on it), and even held this up as the only kind of poetry to be deemed proper and worthy of pursuit. Thus he was forced to consider the point more carefully; to this dispute we owe the essays on naive and sentimental poetry. Here it is argued that both modes of poetry should exist side by side, that each must accord the other equal standing.

With this thought he broke ground for a whole new esthetics: *hellenic*, *romantic*, and all other concepts of this sort may be traced back to his discussion of whether a style is primarily real or ideal.

And thus I slowly grew accustomed to a language which had been totally foreign to me. This was made easier by the fact that it encouraged a higher level of thinking about art and science. I felt much nobler and richer than I had when we were subjected to the indignities of the popular philosophers, and philosophers of another sort for whom I can find no name.

For my further progress I am particularly grateful to Niethammer,[9] who worked patiently with me to unravel the principal riddles, and to develop and explain individual concepts and expressions. My debt then and later to Fichte, Schelling, Hegel, the Humboldt brothers, and Schlegel[10] will be repaid with thanks when I am able to describe—or at least indicate, even sketch—this most important period, the final decade of the last century, from my own point of view.

Judgment through Intuitive Perception

In seeking to penetrate Kant's philosophy,[1] or at least apply it as well as I could, I often got the impression that this good man had a roguishly ironic way of working: at times he seemed determined to put the narrowest limits on our ability to know things, and at times, with a casual gesture, he pointed beyond the limits he himself had set. He had no doubt observed man's precocious and cocky way of making smug, hurried, thoughtless pronouncements based on one or two facts, of rushing to hasty conclusions by trying to impose on the objective world some notion that passes through one's head. Thus our master limits his thinking person to a reflective, discursive faculty of judgment and absolutely forbids him one which is determinative. But then, after he has succeeded in driving us to the wall, to the verge of despair in fact, he makes the most liberal statements and leaves it to us to decide how to enjoy the freedom he allows us. In this sense I view the following passage as particularly significant:

> We can, however, think an understanding which being, not like ours, discursive, but intuitive, proceeds from the *synthetical-universal* (the intuition of the whole as such) to the particular, i.e. from the whole to the parts. . . . It is here not at all requisite to prove that such an *intellectus archetypus* is possible, but only that we are led to the idea of it—which too contains no contradiction—in contrast to our discursive understanding, which has need of images (*intellectus ectypus*) and to the contingency of its constitution.[2]

Here, to be sure, the author seems to point to divine reason. In the moral area, however, we are expected to ascend to a higher realm and approach the primal being through faith in God, virtue, and immortality. Why should it not also hold true in the intellectual area that through an intuitive perception of eternally creative nature we may become worthy of participating spiritually in its creative processes? Impelled from the start by an inner need, I had striven unconsciously and incessantly toward primal image and prototype, and had even succeeded

in building up a method of representing it which conformed to nature. Thus there was nothing further to prevent me from boldly embarking on this "adventure of reason" (as the Sage of Königsberg[3] himself called it).

Doubt and Resignation

When we consider the structure of the universe in its fullest expanse and minutest detail we cannot help but think that the whole rests upon an idea which sets the pattern according to which God creates and works in nature, and nature in God, throughout all eternity. Perception, observation, and reflection will bring us closer to that mystery. We become bold and dare to advance ideas as well; we grow modest and form concepts which may be analogous to that primal source.

Here we meet the real difficulty, one we do not always see clearly: between idea and experience there inevitably yawns a chasm which we struggle to cross with all our might, but in vain. In spite of this we are forever in search of a way to overcome this gap with reason, intellect, imagination, faith, feeling, delusion, and—when all else fails—folly.

In the end, after an honest effort, we will probably find ourselves agreeing with the philosopher[1] who asserts that no idea is fully congruent with experience, although he admits that idea and experience can and must be analogous.

This difficulty in uniting idea and experience presents obstacles in all scientific research: the idea is independent of space and time while scientific research is bound by space and time. In the idea, then, simultaneous elements are closely bound up with sequential ones, but our experience always shows them to be separate; we are seemingly plunged into madness by a natural process which must be conceived of in idea as both simultaneous and sequential. Our intellect cannot think of something as united when the senses present it as separate, and thus the conflict between what is grasped as experience and what is formed as idea remains forever unresolved.

So we might be permitted to take solace in the sphere of poetry, and make some changes in an old song[2] to give it new life:

Thus view with unassuming eyes
The Weaver Woman's masterpiece:
One pedal shifts a thousand strands,

The shuttles back and forward flying,
Each fluent strand with each complying,
One stroke a thousand links commands;
No patchwork, this, of rag and tatter,
Since time began She plots the matter,
So may the Master, very deft,
Insert with confidence the weft.[3]

The Formative Impulse

In his *Critique of Judgment* Kant says of the present research on this important topic:

> As regards the theory of Epigenesis,[1] no one has contributed more either to its proof or to the establishment of the legitimate principles of its application—partly by the limitation of a too presumptuous use of it—than Herr Hofrat Blumenbach.[2]

Such a testimonial from the conscientious Kant inspired me once again to take up Blumenbach's work[3] (which I had actually read earlier, but incompletely). In doing so I discovered that Caspar Friedrich Wolff formed a link between Haller and Bonnet[4] on one side and Blumenbach on the other. To support his theory of epigenesis Wolff had found it necessary to presuppose an organic element which nourished every being destined for life as an organism. He bestowed upon this substance a *vis essentialis,* a force adapted to all that was generated and thus elevated in its own right to the level of a generative power.

This type of terminology proved untenable, for there is always a material quality about such an organic substance, regardless of how much life we impute to it. Basically the word "force" means something purely physical, even mechanical; the question of which organism is to arise out of that substance remains obscure and insoluble. Blumenbach then achieved the ultimate refinement of this term: he anthropomorphized the phrasing of the riddle and called the object of discussion a *nisus formativus,* an impulse, a surge of action which was supposed to cause the formation.

We can examine this assertion more quickly, easily, and perhaps more thoroughly, if we recognize that in considering a present object we must suppose an action prior to it, and in forming a concept of an action we must presume a suitable material for it to act upon. Finally, we must think of this action as always coexisting with the underlying material, the two forever present at one and the same time. Personified, this prodigy confronts us as a god, as a creator and sustainer, whom we are constrained to worship, honor, and praise.

If we now return to philosophy and reconsider evolution[5] and epigenesis, they will strike us as terms which only avoid the issue. Admittedly, the theory of encasement[6] quickly becomes unacceptable to the well-educated. Nonetheless, any theory of accommodation and adaptation will have to presuppose something which adapts and something to which it adapts; if we want to avoid the concept of preformation[7] we will arrive at a concept of predelineation, predetermination, prestabilization, or whatever we wish to call the process which would have to occur before we could perceive a thing.

I will go so far as to assert, however, that when an organism manifests itself we cannot grasp the unity and freedom of its formative impulse without the concept of metamorphosis.

In conclusion, a schematic outline as stimulus to further thought:

$$\left.\begin{array}{ll} & \textit{Matter} \\ \text{Ability} & \\ \text{Power} & \\ \text{Force} & \\ \text{Striving} & \\ \text{Impulse} & \\ & \textit{Form} \end{array}\right\} \textit{Life}$$

A Friendly Greeting

I can no longer conceal a pleasure which has come upon me more than once in recent days. I have a wonderful feeling of being in harmony with serious, productive researchers here and elsewhere. Although they admit the need to postulate and acknowledge something beyond knowing, they do not draw a line the researcher himself is forbidden to cross.

Must I not acknowledge and postulate myself without ever knowing my own nature? Do I not endlessly study myself without ever achieving a grasp of myself, of myself and others? Yet we cheerfully continue to press forward.

The same is true of the world! It may lie before us without beginning or end, the horizon boundless, our surroundings impenetrable—so be it. No limit, no definition, may restrict the range or depth of the human spirit's passage into its own secrets or the world's.

The following bit of light verse should be read and understood in this spirit:

Spontaneous Outburst[1]

"Into the core of Nature"—
O Philistine—
"No earthly mind can enter."
The maxim is fine;
But have the grace
To spare the dissenter,
Me and my kind.
We think: in every place
We're at the center.
"Happy the mortal creature
To whom she shows no more
Than the outer rind,"
For sixty years I've heard your sort announce.
It makes me swear, though quietly;
To myself a thousand times I say:
All things she grants, gladly and lavishly;

Nature has neither core
Nor outer rind,
Being all things at once.
It's yourself you should scrutinize to see
Whether you're center or periphery.

Significant Help Given by an Ingenious Turn of Phrase

In his *Anthropology* (a book to which we will again refer), Dr. Heinroth[1] speaks favorably of my work; in fact, he calls my approach unique, for he says that my thinking works *objectively*. Here he means that my thinking is not separate from objects; that the elements of the object, the perceptions of the object, flow into my thinking and are fully permeated by it; that my perception itself is a thinking, and my thinking a perception. He does not withhold his applause for this approach.

In the next few pages I have tried to describe the ideas which this turn of phrase and the attendant approval aroused in me. I recommend them to the reader who has looked at the passage in question (*Anthropology*, p. 387).

Here, as in earlier volumes,[2] I have followed my intention of describing how I perceive nature, and also showing something of myself, my inner being, my approach to life. In this regard an earlier essay, "The Experiment As Mediator between Object and Subject,"[3] will be found especially helpful.

I must admit that I have long been suspicious of the great and important-sounding task: "know thyself."[4] This has always seemed to me a deception practiced by a secret order of priests who wished to confuse humanity with impossible demands, to divert attention from activity in the outer world to some false, inner speculation. The human being knows himself only insofar as he knows the world; he perceives the world only in himself, and himself only in the world. Every new object, clearly seen, opens up a new organ of perception in us.

But the greatest help comes from our fellow men: they have the advantage of being able to compare us with the world from their own standpoint, and thus they know us better than we ourselves can.

Since reaching the age of maturity, I have always paid strict attention to what others might know of me: from them and in them, as in so many mirrors, I can gain a clearer idea of myself and what lies within me.

Here I exclude adversaries, for they find my existence odious, repudiate my goals, and condemn my means of reaching them as a mere waste of time. Thus I pass them by and ignore them, for they offer no help with the growth which is the point of life. But friends may call attention to my limitations or to the infinite in my being—in either case I listen to them and trust that they will truly instruct me.

What has been said of my *objective thinking* may be applied equally to my *objective poetry*. Certain great motifs, legends, ancient traditions made such an impression on my mind that I could keep them inwardly alive and active for forty or fifty years. They were like a miraculous possession, worthwhile images I often saw renewed in the play of my imagination. There they metamorphosed repeatedly—without changing, they ripened into a purer form, more definite in outline. Of these I will mention only "The Bride of Corinth," "The God and the Bayadere," "The Count and the Dwarves," "The Singer and the Children," and lastly, "Pariah" (soon to be published).[5]

The above will explain my bent for occasional poetry, written when the special features of some situation proved irresistible. One may also note that each of my songs is based on something individual; be the fruit great or small, a certain seed lies within. This is why these songs (especially those of a more definite character) have not been performed for some years now: they require that the performer drop his usual state of neutrality and adopt a point of view, a mood distinctly foreign to his nature; that he deliver the words articulately so that the audience knows what they mean. Verses of a more plaintive sort were easier to accept, and they have became rather popular (along with other such works in German).

My longstanding opposition to the French Revolution is related directly to this; for the above point explains my endless efforts as a poet to grasp that most terrible of all events in both cause and effect. In retrospect, I can realize how my preoccupation over the years with this vast subject has consumed my poetic talent to little purpose. Yet I must admit that this event left such a deep impression on me that I still plan the sequel to *The Natural Daughter,*[6] still give form to this wonderful creation in thought, but lack the courage to work out the details on paper.

Turning now to the quality of objective thought ascribed to me, I also found this approach necessary when I dealt with subjects in the area of natural history. What thread of observation and reflection was left unexplored before the idea of the metamorphosis of plants came to me! My friends will find evidence of this in my *Italian Journey*.[7]

This is also true of my concept that the skull is composed of vertebral bones. I had early recognized the three posterior bones.[8] But it was not until 1790 that I picked up a broken sheep's skull from the dunelike

sands of the Jewish cemetery in Venice, and saw right away that the facial bones could also be traced back to vertebrae, for the transition was clear from the anterior sphenoid bone to the ethmoid bone and the nasal conchae.

For many years I attempted to revise my geological studies in the hope that they and the view associated with them might find some point of agreement with the new and popular idea of plutonism.[9] I had little success with this project, but sudden enlightenment came with the word "objective." I saw clearly that all the objects I had been observing and examining for fifty years necessarily led to the very concept and opinion I now find impossible to abandon. To be sure, I can take the opposite point of view for a while, but to put myself at ease I must always return to my old way of thinking.

Stimulated by these very thoughts, I continued in my self-examination, and found that my whole method relies on derivation. I persist until I have discovered a pregnant point from which several things may be derived, or rather—since I am careful in my work and observations—one which yields several things, offering them up of its own accord. If some phenomenon appears in my research, and I can find no source for it, I let it stand as a problem. This approach has proven quite advantageous over the years. The origin and context of some problem might be impossible to discover; I might have to let it lie for a long time; but at some moment, years later, enlightenment comes in the most wonderful way. Thus I will continue to take the liberty of using these pages to give a historical view of my past experiments and observations, and the way of thought they lead to. This may at least serve as a characterization, a confession of faith in which adversaries will find insight, the like-minded will find help, while the future will find knowledge and—if I succeed—some degree of balance.

A General Observation

In the history of science it is important to note that the first stages of a discovery leave their mark on the course of knowledge; they have a lasting effect in hindering its progress, even paralyzing it.

Admittedly, the occasion for the discovery is quite important, and the first step gives rise to a nomenclature which does no harm in itself. Electricity took its name from amber,[1] and rightly so; but this created an association between amber and electricity, and thus it was a long time before glass was placed side by side with amber and the two were compared.

Every path leading to a new discovery has its own influence on opinion and theory. We can hardly resist the thought that what led us to a phenomenon is also the origin, the cause of the phenomenon. We then persist in this belief instead of taking the opposite approach and putting our first opinion to the test in order to gain the whole.

What would we say of an architect who entered a palace by the side door and then tried to relate everything in his description and drawings to the minor aspect he encountered first? Yet in the sciences this happens every day. We must acknowledge this as historical fact, but it is hard to admit that we ourselves are still caught in these shadows.

Problems[1]

Natural system: a contradictory expression.

Nature has no system; she has—she is—life and development from an unknown center toward an unknowable periphery. Thus observation of nature is limitless, whether we make distinctions among the least particles or pursue the whole by following the trail far and wide.

The idea of metamorphosis deserves great reverence, but it is also a most dangerous gift from above. It leads to formlessness; it destroys knowledge, dissolves it. It is like the *vis centrifuga*,[2] and would be lost in the infinite if it had no counterweight; here I mean the drive for specific character, the stubborn persistence of things which have finally attained reality. This is a *vis centripeta* which remains basically untouched by any external factor. We may recall the genus *Erica*.[3]

But since both forces operate at the same time, any didactic description would have to show them simultaneously—which seems impossible.

There may be no escape from this difficulty without recourse once more to artifice.

Compare the natural sequence of musical notes with the equal temperament[4] within the confines of the octaves. It is actually the temperament which makes truly satisfying music of a higher kind possible, nature notwithstanding.

It would be necessary to introduce a method of discoursing by artifice. A symbolism would have to be established! But who is to do this? And who is to recognize it, once accomplished?

Regarding what botany calls "genera" (in the usual sense of the word), I have always held it impossible to treat one genus like another. I would say there are genera with a character which is expressed throughout all their species; we can approach them in a rational way. They rarely dissolve into varieties, and thus they deserve to be treated with respect. I will mention the gentians, but the observant botanist may add several more.

On the other hand, there are characterless genera in which species may become hard to distinguish as they dissolve into endless varieties. If we make a serious attempt to apply the scientific approach to these, we will never reach an end; instead, we will only meet with confusion, for they elude any definition, any law. I have occasionally ventured to call these the wanton genera, and have even applied this epithet to the rose, although this in no way detracts from its graceful quality. *Rosa canina*[5] may especially deserve this reproach.

Wherever the human being plays a significant role, he acts as a lawgiver: in morality, through his recognition of duty; in the area of religion, by declaring his adherence to a particular conviction about God and things divine, and then by connecting certain analogous outer ceremonies with his conviction. The same thing occurs in government, whether peaceful or warlike: actions and deeds are meaningful only if prescribed by the human being for himself and others. The same is true of art: we have described above how music has yielded to man's spirit; in our own time it is an open secret that the greatest epochs saw the human spirit actively at work in the plastic arts through the most talented artists. In the sciences we find an indication of this in the innumerable attempts to systemize, to schematize. But our full attention must be focused on the task of listening to nature to overhear the secret of her process, so that we neither frighten her off with coercive imperatives, nor allow her whims to divert us from our goal.

Ernst Stiedenroth: *A Psychology in Clarification of Phenomena from the Soul* (Part One, Berlin: 1824)[1]

I always considered myself fortunate if an important book came into my hands at a moment when it coincided with my own work, strengthening and furthering my activity. This was often true of books from antiquity, but contemporary works had the greatest effect, for what lies closest always seems most alive.

In the above book I again met with this pleasant experience. Through the goodness of the author it arrived at the right time, just when I was finally sending the publisher my comments on Purkinje[2] (written several years earlier).

Philosophers specializing in this area will review and judge this book, but I will briefly indicate my own experience with it.

Imagine a twig cast into a gently flowing brook, carried along both captive and willing, perhaps caught for a moment on a stone, perhaps lingering awhile in some bend, but inexorably carried on by the living wave—thus you can imagine how this coherent and stimulating book affected me.

Its author will know best what I really mean by this, for I have often written of the dissatisfaction I felt in my younger years with the doctrine of lower and higher soul forces. In the human spirit, as in the universe, nothing is higher or lower; everything has equal rights to a common center which manifests its hidden existence precisely through this harmonic relationship between every part and itself. The quarrels in antiquity, as well as in modern times, all spring from a division of what God created as one in His realm of nature. We are well enough aware that some skill, some ability, usually predominates in the character of each human being. This leads necessarily to one-sided thinking since man knows the world only through himself, and thus has the naive arrogance to believe that the world is constructed by him and for his sake. It follows that he puts his special skills in the foreground, while seeking to reject those he lacks, to banish them from his own totality. As a correction, he needs to develop all the manifestations of human character— sensuality and reason, imagination and common sense—into

a coherent whole, no matter which quality predominates in him. If he fails to do so, he will labor on under his painful limitations without ever understanding why he has so many stubborn enemies, why he sometimes meets even himself as an enemy.

Thus a man born and bred to the so-called exact sciences, and at the height of his ability to reason empirically, finds it hard to accept that an exact sensory imagination might also exist, although art is unthinkable without it. This is also a point of contention between followers of emotional religion and those of rational religion: while the latter refuse to acknowledge that religion begins with feeling, the former will not admit the necessity for religion to develop rationally.

Stiedenroth's book aroused these and similar thoughts in me. Every reader will find it useful in his own way; I expect that continued reading will supply me with a text for further positive comments.

In connection with the above, here is a passage in which the area of thinking directly adjoins the field of poetry and visual art:

> It follows from the above that thought presupposes reproduction. In every case, the reproduction depends on the clarity of the concept. On the one hand, effective thinking depends on adequate sharpness and clarity in each concept; on the other, it depends on richness and a suitable coherence in what is to be reproduced. To the extent it is suited for thought, this coherence in the subject to be reproduced arises largely in thought itself, insofar as correspondences emerge from the several parts and enter into a special coherence through the close relationship of their content. Thus any sort of effective thinking will depend entirely on the aptness of the reproduction we can form. Anyone lacking the right capacity in this regard will never accomplish anything right. Those with meager reproductions will reveal poverty of spirit; those with one-sided reproductions will think one-sidedly; those with disorderly and confused reproductions will show the lack of a clear mind; etc. Thought does not arise from nothing, but presupposes the prior existence of adequate form and coherence. Thought in the narrower sense presupposes a coherence and conceptual order suited to the subject—accompanied, of course, by the necessary thoroughness. (Stiedenroth, p. 140)

Natural Philosophy

A passage from d'Alembert's[1] introduction to the great French encyclopedia struck us as noteworthy. Although space does not allow for a translation here, it begins on page X of the quarto edition with the words, "A l'égard des sciences mathématiques," and ends on page XI with, "étendu son domaine." The end of the passage refers to the beginning, and contains a great truth: everything in science is based on the content, substance, and usefulness of a given axiom, and on the clarity of what is proposed. We, too, are convinced that this great demand must be met not only in mathematics, but also in the sciences, the arts, and life itself.

It cannot be said often enough: the poet as well as the visual artist should begin by seeing whether his chosen subject has the potential to produce a complex, complete, and satisfactory work. If this is overlooked, all else is in vain: metric foot and rhymed word, brush stroke and chisel mark—all are wasted. And even if technical mastery might bedazzle the sensitive viewer for a time, he will soon begin to sense the lack of spirit afflicting all things false.

Thus in artistic work, as in scientific and mathematical work, the essential element is the underlying truth which is disclosed not so much by speculative thought as by practical application; here we find the touchstone for what is born of the spirit, what an inner sense recognizes as true. When a man arrives at the conviction that his proposals have merit, he will turn to the outer world, asking that it not only agree with his ideas, but also conform to them, obey them, realize them. Then, and only then, will he learn whether his enterprise is wrong or his age lacks the ability to recognize the truth.

But there remains one trait by which we can most accurately distinguish the true from the illusory. The true always bears fruit, bringing some good to those who cultivate it; the false, in and of itself, lies dead and sterile; we may even see it as a kind of necrosis where the withered part prevents the living part from healing the sickness.

Analysis and Synthesis

In this year's third lecture on the history of philosophy[1] Mr. Victor Cousin bestows high praise on the eighteenth century for its emphasis on the analytic method in science and for the care it took to avoid premature synthesis, i.e. hypotheses. However, after giving almost unqualified approval to this approach, he notes that synthesis should not be excluded entirely since its use—albeit with caution—is sometimes necessary.

Consideration of these statements quickly led us to the thought that this is an area where the nineteenth century needs to do more: the friends and followers of science must note that we have failed to test, develop, and clarify false syntheses, i.e., hypotheses handed down to us from the past. We have failed to restore to the human spirit its ancient right *to come face to face with nature.*

Here we will cite two of these false syntheses by name: the decomposition of light and the polarization of light.[2] Although often repeated by men of science, these two empty phrases say nothing to the thoughtful observer.

It is not enough that we apply the analytic approach to the observation of nature; i.e., that we refine as many details as possible out of a given object and thereby familiarize ourselves with it. We should go on to apply the same analysis to existing syntheses so that we may discover whether a valid method has been applied in creating them.

Thus we have subjected Newton's approach to intensive analysis.[3] He made the mistake of using a single phenomenon,[4] and an overrefined one at that, as the foundation for a hypothesis supposed to explain the most varied and far-reaching events in nature.

To develop our theory of color we used the analytic approach; insofar as possible we presented every known phenomenon in a certain sequence so that we could determine the degree to which all might be governed by a general principle. It is our hope that this will help point the way for the nineteenth century as it carries out the duty we mentioned above.

We used a like approach in presenting the various phenomena created in double reflection.[5] We bequeath both these efforts to some distant future in the knowledge that we have redirected our experiments to nature and thus truly set them free.

Let us proceed to another more general observation. A century has taken the wrong road if it applies itself exclusively to analysis while exhibiting an apparent fear of synthesis: the sciences come to life only when the two exist side by side like exhaling and inhaling.

A false hypothesis is better than none at all, for the mere fact that it is false does no harm. But when such a hypothesis establishes itself, when it finds general acceptance and becomes something like a creed open to neither doubt nor test, it is an evil under which centuries to come will suffer.

Here Newton's theory[6] may serve as an example. Objections to its shortcomings arose during Newton's own lifetime, yet these objections were smothered under the weight of his great accomplishments in other areas and his standing in social and learned circles. But the French are most to blame in disseminating and rigidifying this theory.[7] It will be their task in the nineteenth century to rectify their error by encouraging a fresh analysis of that tangled and ossified hypothesis.

An important point is apparently overlooked when analysis is used alone: every analysis presupposes a synthesis. A pile of sand cannot be analyzed, but if the pile contains grains of different materials (sand and gold for instance), an analysis might be made by washing it: then the light grains will wash away and the heavy ones remain.

Thus modern chemistry depends largely on separating what nature has united. We do away with nature's synthesis so that we may learn about nature through its separate elements.

What higher synthesis is there than a living organism? Why would we submit ourselves to the torments of anatomy, physiology, and psychology if not to reach some concept of the whole, a concept which can always restore itself to wholeness no matter how it is torn to pieces?

Therefore a great danger for the analytical thinker arises when he *applies his method where there is no underlying synthesis*. In that case his work will be a true labor of the Danaids,[8] and we can find the saddest examples of this. For in essence he is simply working to return to the synthesis. But if no synthesis underlies the object of his attention he will labor in vain to discover it. All his observations will only prove more and more an obstruction as their number increases.

Thus the analytical thinker ought to begin by examining (or rather, by noting) whether he is really working with a hidden synthesis or only an aggregation, a juxtaposition, a composite, or something of the sort. The areas of knowledge which have ceased to develop raise such doubts. It might be possible to make some useful observations of this sort about the fields of geology and meteorology.[9]

Toward a General Comparative Theory[1]

When a science falters and comes to a standstill despite the best efforts of many researchers, it can often be seen that the fault lies in a certain traditional concept of things, a conventional terminology, which the great majority accepts and follows unconditionally, and from which even thoughtful people depart only occasionally and under limited circumstances.

To be as clear as possible I will proceed from this general observation directly to the point: the progress of natural philosophy has been obstructed for many centuries by the conception that a living being is created for certain external purposes and that its form is so determined by an intentional primal force. This idea still holds us back, although some have voiced vehement opposition to it and drawn attention to the stumbling blocks it creates.

In itself this way of thinking may be full of piety,[2] give pleasure to people of a certain temperament, and be indispensable for certain ways of thought. I find it neither advisable nor possible to refute it as a whole. It is, if I may say so, a trivial idea; like all such things it is trivial precisely because human nature finds it comfortable and satisfying.

Man is in the habit of valuing things according to how well they serve his purposes. It lies in the nature of the human condition that man must think of himself as the last stage of creation. Why, then, should he not also believe that he is its ultimate purpose? Why should his vanity not be allowed this small deception? Given his need for objects and his use for them, he draws the conclusion that they have been created to serve him. Why should he not resolve the inner contradictions here with a fiction rather than abandon the claims he holds so dear? Why should he not ignore a plant which is useless to him and dismiss it as a weed, since it really does not exist for him? When a thistle springs up to increase his toil in the fields he blames it on the curse of an angry god or the malice of a spiteful demon rather than considering it a child sprung from all of nature, one as close to her heart as the wheat he tends so carefully and values so highly. Indeed it may be noted that

even the most just of men, those who believe they are the most selfless, are often able to rise only to the point of expecting all things to benefit man in some indirect form rather than directly, e.g., through the discovery of a natural force which has applications in medicine or some other area.

Moreover, in himself and others he justifiably puts the greatest value on actions and deeds which are intentional and purposeful. It follows that he will attribute intent and purpose to nature, for he will be unable to form a larger concept of nature than of himself.

He further believes that everything that exists is there for him, is there only as a tool and aid to his own existence. It follows as a matter of course that when nature provides tools for him, it acts with an intention and purpose equal to his own in manufacturing them. The sportsman who has a hunting rifle made will praise the forethought shown by Mother Nature in preparing the dog to fetch his prey.

There are other reasons for man's general difficulty in abandoning this concept. However, the simple example of botany will show that the scientist must leave this view behind if he wishes to make progress in thinking about things in general. The brightest and fullest flowers, the most delicious and attractive fruits, have no more value to the science of botany than a lowly weed in its natural setting or a dried and useless seed capsule, and may even be of less value in a certain sense.

Thus the scientist will have to rise above this trivial concept. Even if he cannot rid himself of it as a human being, he must at least make every effort to shed it as a scientist.

Here this observation about the scientist has only a general application. However, another observation based on the first will have a more specific application. In relating all things to himself man is forced to lend these things an inner purpose which is manifested externally, and all the more so because nothing alive can be imagined as existing without a complete structure. Since this complete structure develops inwardly in a fully specialized and specific way, it needs an external environment which is just as specialized. It can only exist in the outer world under certain conditions and in certain contexts.

Thus we find the most varied forms of animal life stirring on the earth, in the water, and in the air. The common view is that these creatures have received their appendages for the purpose of making various movements and thereby supporting their particular form of existence. But will we not show more regard for the primal force of nature, for the wisdom of the intelligent being usually presumed to underlie it, if we suppose that even its power is limited, and realize that its forms are created by something working from without as well as from within? The statement "The fish exists for the water" seems to me to say far less than "The fish exists in the water and by means of the water."

The latter expresses more clearly what is obscured in the former; i.e., the existence of a creature we call "fish" is only possible under the conditions of an element we call "water," so that the creature not only exists in that element, but may also evolve there.

The same principle holds true of all other creatures. An initial and very general observation on the outer effect of what works from within and the inner effect of what works from without would therefore be as follows: the structure in its final form is, as it were, the inner nucleus molded in various ways by the characteristics of the outer element. It is precisely thus that the animal retains its viability in the outer world; it is shaped from without as well as from within. And this is all the more natural because the outer element can shape the external form more easily than the internal form. We can see this most clearly in the various species of seal, where the exterior has grown quite fishlike even though the skeleton still retains all the features of a quadruped.

We show disrespect neither for the primal force of nature nor for the wisdom and power of a creator if we assume that the former acts indirectly, and that the latter acted indirectly at the beginning of all things. Is it not fitting that this great force should bring forth simple things in a simple way and complex things in a complex way? Do we disparage its power if we say it could not have brought forth fish without water, birds without air, other animals without earth, that this is just as inconceivable as the continued existence of these creatures without the conditions provided by each element? Will we not attain a more satisfactory insight into the mysterious architecture of the formative process, now widely recognized to be built on a single pattern, by examining and comprehending this single pattern more fully and then looking into the following question: how does a surrounding element, with its various specific characteristics, affect the general form we have been studying? How does the form, both determined and a determinant, assert itself against these elements? What manner of hard parts, soft parts, interior parts, and exterior parts are created in the form by this effect? And, as indicated before, what is wrought by the elements through all their diversity of height and depth, region and climate?

Much research has already been done on these points. This needs only to be brought together and applied, but in accordance with the method described above.

How admirable that nature must use the same means to produce a creature as it does to sustain it! We progress on our path as follows: first we viewed the unstructured, unlimited element as a vehicle for the unstructured being, and now we will raise our observation to a higher level to consider the structured world itself as an interrelationship of many elements. We will see the entire plant world, for example, as an vast sea which is as necessary to the existence of individual insects

as the oceans and rivers are to the existence of individual fish, and we will observe that an enormous number of living creatures are born and nourished in this ocean of plants. Ultimately we will see the whole world of animals as a great element in which one species is created, or at least sustained, by and through another.[3] We will no longer think of connections and relationships in terms of purpose and intention. This is the only road to progress in understanding how nature expresses itself from all quarters and in all directions as it goes about its work of creation. As we find through experience, and as the advance of science has shown, the most concrete and far-reaching benefits for man come from an intense and selfless effort which neither demands its reward at week's end like a laborer, nor lies under any obligation to produce some useful result for mankind after a year, a decade, or even a century.

Observation on Morphology in General

Morphology may be viewed as a theory in and of itself, or as a science in the service of biology. As a whole it is based on natural history,[1] drawing from it the phenomena with which it works. It is also based on the anatomy of all living bodies, and especially on zootomy.

Since its intention is to portray rather than explain, it draws as little as possible on the other sciences ancillary to biology, although it ignores neither the relationships of force and place in physics nor the relationships of element and compound in chemistry. Through its limitations it becomes, in fact, a specialized set of principles. Without exception it considers itself the handmaiden of biology, working together with other subsidiary sciences.

In morphology we propose to establish a science new not because of its subject matter, which is already well known, but because of its intention and method, which lends its principles their unique form and gives it a place among the other sciences. Since this is a new science we will start with a discussion of the latter point, the connection of morphology with other related sciences. We will then set forth its content and the method used in presenting this content.

Morphology may be said to include the principles of structured form and the formation and transformation of organic bodies; thus it belongs to a particular group of sciences, each of which its has its own purpose. We will now review these sciences.

Natural history assumes that the variety of forms in the organic world is a known phenomenon. It recognizes that this great variety also shows a certain consistency which is partly universal and partly specific. It not only records the bodily structures known to it, but it arranges them, sometimes in groups and sometimes in sequence, according to the forms that are observed and the characteristics that are sought out and recognized. Thus it enables us to survey an enormous mass of material. Its work has two goals: partly to pursue the discovery of new subjects, and partly to arrange these subjects more in conformity with nature and their own characteristics, eliminating all that is arbitrary insofar as possible.

While natural history concentrates on the surface appearance of forms and views them as a whole, anatomy requires a knowledge of the inner structure; it treats the human body as the most worthy subject for dissection, and the one most in need of the aid only a thorough knowledge of structure can offer.[2] A certain amount of work has been done on the anatomy of other living structures, but this is so scattered, so incomplete, and even so erroneous in many cases, that the collection of material remains almost useless to the scientific researcher.

In seeking to pursue and broaden the empirical observations of natural history, or draw them together for use, researchers have called on other areas of science, turned to closely related fields, or even formulated their own approaches. All this has been done and is still being done to fulfill the need for a general overview in biology (although, as human nature would have it, in a manner which is too one-sided). Nonetheless, an excellent foundation has been laid for the biologist of the future.

From the physicist (in the strictest sense of the word) the theory of organic nature has been able to acquire only a knowledge of the general relationship between forces, and the location and orientation of these forces in the particular area under study. The application of mechanical principles to organisms has merely made us all the more aware of the perfection of living beings, and we might almost say that the less applicable mechanical principles become, the more an organism grows in perfection.

In this area, as in others, we owe much to the chemist who sets form and structure aside and simply observes the character of materials and how they form compounds. Our debt to him will increase in the future, for recent discoveries have made the most refined analyses and syntheses possible, thus holding out the hope that we will be able to approximate the infinitely subtle processes of the living organism itself. Just as we have already created an anatomical biology through careful observation of structure, we may also look forward to a physical-chemical biology in the course of time. We may hope that these two sciences will progress so that each becomes capable of achieving this goal independently.

However, since both sciences are altogether analytical in character, and chemical compounds are based only on processes of separation, it is natural that these approaches to the study and understanding of organisms do not satisfy everyone. Many will prefer to start with a unified whole, develop the parts from it, and then retrace the parts directly to the whole. The nature of the organism supplies us with the best reason for doing this: the most perfect organism appears before us as a unified whole, discrete from all other beings. We know that we ourselves are such a whole; we experience the fullest sense of well-being when we are unaware of our parts and conscious only of the

whole itself. The existence of organic nature is possible only insofar as organisms have structure, and these organisms can be structured and maintained as active entities solely through the condition we call "life." Thus it was natural that a science of physiology should be established in an attempt to discover the laws an organism is destined to follow as a living being. For the sake of argument this life was quite properly viewed as derived from a force,[3] an assumption justified and even necessary because life in its wholeness is expressed as a force not attributable to any individual part of an organism.

In thinking of an organism as a whole, or of ourselves as a whole, we will shortly find two points of view thrust upon us. At times we will view man as a being grasped by our physical senses, and at times as a being recognized only through an inner sense or understood only through the effects he produces.

Thus physiology falls into two parts which are not easily separated, i.e., into a physical part and a spiritual part. In reality these are inseparable, but the researcher in this field may start out from one side or the other and thus lend the greater weight to one *or* the other.

However, any of the sciences listed here would require our full attention; indeed, the pursuit of a specific area in just one of them would take an entire lifetime. An even greater difficulty lies in the fact that these sciences are cultivated almost exclusively by physicians, and although they address a certain aspect of their science by adding to its store of empirical observation, the need for application prevents them from extending its frontiers.

Thus we realize that much remains to be done before the biologist who seeks to combine all these views can consolidate them into one and achieve an understanding commensurate with his grand subject, insofar as this is permitted to the human spirit. To achieve this requires a focused activity on all sides, an activity which has been and continues to be in evidence. Progress in this activity would be more rapid and certain if each researcher would pursue it in his own way (but not one-sidedly), if he would joyfully acknowledge his colleagues' every accomplishment instead of putting his own views uppermost, as is usually the case.

Now that we have presented the various sciences contributing to the work of the biologist, and shown their relationship, it is time for morphology to prove its legitimacy as a science in its own right.

Others agree with this. It must prove its legitimacy as an independent science by choosing a subject other sciences deal with only in passing, by drawing together what lies scattered among them and establishing a new standpoint from which the things of nature may be readily observed. The advantages of morphology are that it is made up of widely recognized elements, it does not conflict with any theory, it does not

need to displace something else to make room for itself, and it deals with extremely significant phenomena. Its arrangement of phenomena calls upon activities of the mind so in harmony with human nature, and so pleasant, that even its failures may prove both useful and charming.

The Enterprise Justified (From *On Morphology*)[1]

When in the exercise of his powers of observation man undertakes to confront the world of nature, he will at first experience a tremendous compulsion to bring what he finds there under his control. Before long, however, these objects will thrust themselves upon him with such force that he, in turn, must feel the obligation to acknowledge their power and pay homage to their effects. When this mutual interaction becomes evident he will make a discovery which, in a double sense, is limitless: among the objects he will find many different forms of existence and modes of change, a variety of relationships livingly interwoven; in himself, on the other hand, a potential for infinite growth through constant adaptation of his sensibilities and judgment to new ways of acquiring knowledge and responding with action. This discovery produces a deep sense of pleasure and would bring the last touch of happiness in life if not for certain obstacles (within and without) which impede our progress along this beautiful path to perfection. The years, providers at first, now begin to take; within our limits we are satisfied with what we have gained and enjoy it all the more quietly since it seldom meets with any genuine, open and cordial expression of interest from without.

How few are those who feel themselves inspired by what is really visible to the spirit alone! Our senses, our feelings, our temperament exercise far greater power over us—and rightly so, since life is our lot rather than reflection.

Unfortunately, however, even those devoted to cognition and knowledge rarely display the degree of interest we would hope to find. Anything arising from an idea and leading back to it is viewed as something of an encumbrance by the man of a practical mind who notes details, observes precisely, and draws distinctions. In his own way he feels at home in his labyrinth and has no interest in a thread that might more quickly lead him through it; a substance uncoined and uncountable seems a burdensome possession to such a person. On the other hand, one who has a higher vantage point is quick to disdain detail and create a lethal generality by lumping together things which live only in separation.

We have long found ourselves in the midst of this conflict, in the course of which much has been accomplished, much destroyed. Had the hour of danger just past[2] not brought home to us the value of the written record, I would never have been tempted to entrust my views on nature to this fragile vessel on the ocean of opinion.

Therefore let what I often dreamt of as a book when I was filled with the high hopes of youth now appear as an outline, as a fragmentary collection. May it work and serve as such.

This, in brief, is what I would say in seeking the good will of my contemporaries for these partially finished sketches which date back many years. Anything further will best be introduced as our enterprise unfolds.

Jena, 1807

The Purpose Set Forth (From *On Morphology*)

In observing objects of nature, especially those that are alive, we often think the best way of gaining an insight into the relationship between their inner nature and the effects they produce is to divide them into their constituent parts. Such an approach may, in fact, bring us a long way toward our goal. In a word, those familiar with science can recall what chemistry and anatomy have contributed toward an understanding and overview of nature.

But these attempts at division also produce many adverse effects when carried to an extreme. To be sure, what is alive can be dissected into its component parts, but from these parts it will be impossible to restore it and bring it back to life. This is true even of many inorganic substances, to say nothing of things organic in nature.

Thus scientific minds of every epoch have also exhibited an urge to understand living formations as such, to grasp their outward, visible, tangible parts in context, to see these parts as an indication of what lies within and thereby gain some understanding of the whole through an exercise of intuitive perception. It is no doubt unnecessary to describe in detail the close relationship between this scientific desire and our need for art and imitation.

Thus the history of art, knowledge, and science has produced many attempts to establish and develop a theory which we will call "morphology." The historical part of our discourse[1] will deal with the different forms in which these attempts have appeared.

The Germans have a word for the complex of existence presented by a physical organism: *Gestalt* [structured form]. With this expression they exclude what is changeable and assume that an interrelated whole is identified, defined, and fixed in character.

But if we look at all these *Gestalten*, especially the organic ones, we will discover that nothing in them is permanent, nothing is at rest or defined—everything is in a flux of continual motion. This is why German frequently and fittingly makes use of the word *Bildung* [formation] to describe the end product and what is in process of production as well.

Thus in setting forth a morphology we should not speak of *Gestalt*, or if we use the term we should at least do so only in reference to the idea, the concept, or to an empirical element held fast for a mere moment of time.

When something has acquired a form it metamorphoses immediately to a new one. If we wish to arrive at some living perception of nature we ourselves must remain as quick and flexible as nature and follow the example she gives.

In anatomy, when we dissect a body into its parts, and further separate these parts into their parts, we will at last arrive at elementary constituents called "similar parts." These will not concern us here. Instead we will concentrate on a higher principle of the organism, a principle we will characterize as follows.

No living thing is unitary in nature; every such thing is a plurality. Even the organism which appears to us as individual exists as a collection of independent living entities. Although alike in idea and predisposition, these entities, as they materialize, grow to become alike or similar, unalike or dissimilar. In part these entities are joined from the outset, in part they find their way together to form a union. They diverge and then seek each other again; everywhere and in every way they thus work to produce a chain of creation without end.

The less perfect the creation, the more its parts are alike or similar and the more they resemble the whole. The more perfect the creation the less similar its parts become. In the first instance the whole is like its parts to a degree, in the second the whole is unlike its parts. The *more similar the parts, the less they will be subordinated to one another.* Subordination of parts indicates a more perfect creation.

No matter how well thought out, generalities always contain an element of incomprehensibility if we find no application for them or are unable to supply illustrative examples. Since our entire treatise is devoted to presenting and developing ideas and principles of this type, we will begin by indicating only a few such examples.

Although a plant or tree seems to be an individual organism, it undeniably consists only of separate parts which are alike and similar to one another and to the whole. How many plants are propagated by runners! In the least variety of fruit tree the eye puts forth a twig which in turn produces many identical eyes; propagation through seeds is carried out in the same fashion. This propagation occurs through the development of innumerable identical individuals out of the womb of the mother plant.

Here it is immediately apparent that the secret of propagation by seeds is already present in the principle cited above, and upon closer consideration we will find that even the seed, seemingly a single unity, is itself a collection of identical and similar entities. The bean is usually

offered as a good example of the process of germination. If we take a bean in its completely undeveloped state prior to germination, and cut it open, we will first find two seed leaves. These are not to be compared to a placenta, for they are two genuine leaves: though distended and stuffed with a mealy substance, they also turn green when given light and air. In addition we will discover the presence of plumules which are again two leaves capable of further and more extensive development. We may also observe that behind every leaf stalk there is an eye, if not actual then at least in latent form. Thus even in the seed, seemingly simple, we find a collection of several individual parts which we may characterize as alike in idea and similar in appearance.

What is alike in idea may manifest itself in empirical reality as alike, or similar, or even totally unalike and dissimilar: this gives rise to the ever-changing life of nature. It is this life of nature which we propose to outline in these pages.

By way of further introduction we will cite an example from the lowest level of the animal kingdom. There are infusoria which we perceive as fairly simple in form when they move about through moisture. When the moisture evaporates, however, they burst and pour forth a number of spores. Apparently this dispersion into spores would have occurred naturally in the moisture, thereby producing descendants without number.

Plants and animals in their least perfect state are scarcely to be differentiated. Hardly perceptible to our senses, they are a pinpoint of life, mutable or semimutable. Are these beginnings—determinable in either direction—destined to be transformed by light into plant, or by darkness into animal? This is a question we would not trust ourselves to answer no matter how well we are supplied with relevant observations and analogies. We can say, however, that the creatures which gradually emerge from this barely differentiated relationship of plant and animal pursue diametrically opposite paths in their development toward perfection. Thus plants attain their final glory in the tree, enduring and rigid, while the animal does so in man by achieving the highest degree of mobility and freedom.

The above axiom concerning the coexistence of multiple identical and similar entities leads to two further cardinal principles of the organism: propagation by bud and propagation by seed. In fact, these principles are simply two ways of expressing the same axiom. We will seek to trace these two paths through the entire realm of organic nature and in the process will find that many things fall vividly into place.

When considering the vegetative model we are presented immediately with a vertical orientation. The lower position is occupied by the root which works into the earth, belongs to the moisture and to the darkness. The stem, the trunk, or whatever may serve in its place, strives upward

in exactly the opposite direction, toward the sky, the light, and the air.

When we then consider this miraculous structure and become familiar with how it rises upward, we will once more meet an important principle of structure: life is unable to work at the surface or express its generative powers there. The whole activity of life requires a covering which protects it against the raw elements of its environment, be they water or air or light, a covering which preserves its delicate nature so that it may fulfill the specific purpose for which it is inwardly destined.

Whether the covering takes the form of bark, skin, or shell, anything that works in a living way must be covered over. And thus everything turned toward the external world gradually falls victim to an early death and decay. The bark of trees, the skin of insects, the hair and feathers of animals, even the epidermis of man, are coverings forever being shed, cast off, given over to non-life. New coverings are constantly forming beneath the old, while still further down, close to this surface or more deeply hidden, life brings forth its web of creation.

Jena, 1807

The Content Prefaced
(From *On Morphology*)

Of the present collection only the essay on the metamorphosis of plants has been in print before. Appearing alone in 1790, it met with a cold, almost hostile reception. This resistance, however, was entirely natural: the theory of encasement, the concept of preformation,[1] of successive development undergone by things dating from the time of Adam, had by and large captivated even the best minds. Moreover Linnaeus, focusing on plant formation in particular, had decisively and authoritatively initiated a brilliant conceptual approach more suited to the spirit of the time.

Thus my honest effort remained entirely without effect. Content to have found a direction for my own quiet path, I simply made more careful note of the relationship and interaction between normal and abnormal phenomena and, at the same time, paid close attention to the detail so generously provided by empirical observation. In addition I spent an entire summer in a series of experiments to find out how fruiting may be prevented by too much nourishment or accelerated by deprivation.

I availed myself of the opportunity to illuminate or darken a greenhouse at will to learn about the effect of light on plants;[2] my principal concern was with the phenomena of fading and bleaching. I also did experiments with panes of colored glass.

After acquiring enough skill in judging most instances of organic change and transformation in the plant world, and discerning and deducing the sequence of forms, I felt further obliged to learn more about the metamorphosis of insects.[3]

No one will dispute that this metamorphosis is a fact: the life of such creatures is a continual transformation, one which is clear and obvious. I had retained my earlier knowledge of this subject, based on years of raising silkworms. I now broadened it by observation of various genera and species from egg to moth; I also had drawings made, the most worthwhile of which I still possess.

Here I found no conflict with what is stated in treatises on the subject.

I needed only to work out a schematic table whereby the individual observations could be arranged in sequence and the wonderful life of these creatures surveyed with clarity.

I will also seek to give an account of these efforts, one which is unconstrained since my view is not in contradiction to any other.

In the pursuit of these studies I turned my attention to the comparative anatomy of animals, especially mammals. There was already great interest in this area. Buffon and Daubenton achieved much. Camper appeared in a meteoric blaze of intelligence, science, talent and industry, Sömmerring showed himself to be worthy of admiration, and Merck brought his always active endeavors to bear on this subject.[4] I had an excellent relationship with all three, with Camper by letter and with the other two in person (a contact which continued even after we parted).

The study of physiognomy required attention to both definition and mutability of form; this point also stimulated much work and discussion with Lavater.[5]

Later, during my frequent and extended visits in Jena, Loder's[6] inexhaustible talents as a teacher quickly provided me the pleasure of some insight into animal and human formation.

The method I had adopted in the observation of plants and insects served to guide me on this path as well, for in distinguishing and comparing forms it was also necessary to discuss formation and transformation, each in their turn.

Nonetheless, that era was more confused than can be imagined today. It was maintained, for example, that if man could learn to walk about comfortably on all fours, bears might become human after standing upright for a time. The audacious Diderot ventured certain suggestions about how goat-footed fauns could be bred to sit in livery atop the coaches of the great and wealthy as a special mark of pomp and distinction.[7]

The distinction between man and animal long eluded discovery. Ultimately it was believed that the definitive difference between ape and man lay in the placement of the ape's four incisors in a bone clearly and physically separate from other bones.[8] Thus the whole of science, in jest or in earnest, vacillated between attempts to prove what was half true and attempts to lend the semblance of truth to what was false—but all with the purpose of keeping itself occupied and sustaining itself through whimsical and willful activity. The greatest confusion, however, arose from the controversy over whether beauty was something real and inherent in objects, or relative, determined by convention, even individually ascribable to the one who beholds and recognizes it.

Meanwhile I had devoted my full energies to the study of osteology, for in the skeleton the unmistakable character of every form is preserved

conclusively and for all time. I surrounded myself with a collection of older and more recent remains, and on trips I carefully looked through museums and small collections for creatures whose formation as a whole, or in part, could prove instructive to me.

In the process I was soon obliged to postulate a prototype against which all mammals could be compared as to points of agreement or divergence. As I had earlier sought out the archetypal plant I now aspired to find the archetypal animal; in essence, the concept or idea of the animal.

My laborious and painstaking research was made easier, even sweetened, when Herder undertook to set down his ideas on the history of mankind.[9] Our daily conversation was concerned with the primal origins of the water-covered earth and the living creatures which have evolved on it from time immemorial. Again and again we discussed the primal origin and its ceaseless development; through mutual sharing and debate we daily refined and enriched our store of scientific knowledge.

This topic which occupied me so intensely was also the subject of lively discussions with other friends, and such conversations had a mutually beneficial effect. Indeed, it is perhaps not presumptuous to think that much of what grew out of those discussions and spread in the sciences as tradition is now bearing fruit. We may now enjoy these fruits even though the garden from which the grafts were taken is not always given credit.

With the more frequent application of empirical observation and deepened philosophical approach of today many things have become common knowledge which were inaccessible to me and my colleagues when the following essays were written. Thus, although their contents may now seem superfluous, they should be considered in the light of history as witness to a quiet, consistent, and unrelenting effort.

Excerpt from "Studies for a Physiology of Plants"[1] [A Schematic Fragment]

I.

To arrange things in order is a large and difficult undertaking.

To know in an orderly way demands exact knowledge of each individual object.

Attention to its character; i.e., differences and similarities.

This alone requires far more than sensory observation and memory.

Insight into its character and judgment of this character.

Striving of the human spirit to make a whole of the objects it observes.

Human impatience to proceed without sufficient preparation.

Too much haste in reaching conclusions.

This is not always to be criticized.

Observations made by various epochs.

The earlier ones are less complete.

Those who aspire to scientific knowledge will start out without feeling a need to widen the horizons of their thought and vision.

Those working with the sciences feel this need only later.

Generalities are frequently used today. The botanical gardener (almost like a simple workman) encounters the most difficult problems in the course of his work, but because he does not know how to solve them, he must either settle for mere words or fall into a kind of astonished confusion.

Thus it is well to be prepared for serious questions and serious answers right from the start.

To reassure ourselves about this and ease our minds, we can say that one should never ask nature a question that one cannot answer oneself. In the question lies the answer, the feeling that it is possible to think about some point, or understand it intuitively.

Of course, different types of people ask different types of questions.

To orient ourselves to these different types, we will classify them as follows:

Utilitarian
Seeking knowledge
Intuitively perceptive
Comprehensive

1. The utilitarians, who seek and demand a use for things, are the first, as it were, to mark out the boundaries of a scientific field; they are the first to take hold of its practical aspect. Their empirical knowledge lends them self-assurance, and their need gives them a certain breadth.

2. Those seeking knowledge are obliged to have a quiet, objective gaze, restless curiosity, and clear understanding. They are always related to the utilitarians, for their scientific work is applied only to predefined fields.

3. The intuitively perceptive have already reached a creative stage, for as knowledge undergoes intensification it begins to demand intuitive perception; it turns into intuitive perception without our noticing. The seekers of knowledge may cross themselves and bless themselves against imagination as often as they wish—before they know it, they will have to call on imagination's creative power for help.

4. The comprehensive, whom vanity might call creators, are productive in the highest degree. Since they start with ideas, they express the unity of the whole, and it may then become nature's job to fit itself somehow into this idea.

Metaphor derived from paths.

Example of the aqueduct[2] to distinguish the fantastic from the ideal.

Example of the dramatic poet.

Productive power of the imagination combined with all possible reality.

In science we must understand clearly that we work in these four regions.

We must always be conscious of which region we are in at any given time.

We should always feel as free to move openly and comfortably in one region as in another.

This will make it possible to recognize and separate the objective and subjective elements of the discussion before we begin. This way, at least, there is hope of establishing trust.

II. Genetic Method[3]

It is obvious that our discussions will take place mainly on the borderline between the second and third regions; we will move consciously from one to the other.

Normally the seekers of knowledge will instinctively turn to the intuitively perceptive for help, although in theoretical matters they sometimes take a wrong teleological turn back to the utilitarians (among whom we include all the scientists who work to glorify God).

The genetic method makes the relationship of the two regions clear and useful.

If I look at the created object, inquire into its creation, and follow this process back as far as I can, I will find a series of steps. Since these are not actually seen together before me, I must visualize them in my memory so that they form a certain ideal whole.

At first I will tend to think in terms of steps, but nature leaves no gaps, and thus, in the end, I will have to see this progression of uninterrupted activity as a whole. I can do so by dissolving the particular without destroying the impression itself.

Rough separation into dynamic elements.

Attempt to refine this.

Attempt to discover further intermediate points.

If we imagine the outcome of these attempts, we will see that empirical observation finally ceases, intuitive perception of the developing organism begins, and the idea is brought to expression in the end.

Example of a city as the work of man.

Example of the metamorphosis of insects[4] as the work of nature.

The principle of plant metamorphosis in its full meaning.

The Metamorphosis of Plants[1]

Introduction

1. Anyone who has paid even a little attention to plant growth will readily see that certain external parts of the plant undergo frequent change and take on the shape of the adjacent parts—sometimes fully, sometimes more, and sometimes less.

2. Thus, for example, the single flower most often turns into a double one when petals develop instead of stamens and anthers; these petals are either identical in form and color to the other petals of the corolla, or still bear visible signs of their origin.

3. Hence we may observe that the plant is capable of taking this sort of backward step, reversing the order of growth. This makes us all the more aware of nature's regular course; we will familiarize ourselves with the laws of metamorphosis by which nature produces one part through another, creating a great variety of forms through the modification of a single organ.

4. Researchers have been generally aware for some time that there is a hidden relationship among various external parts of the plant which develop one after the other and, as it were, one out of the other (e.g., leaves, calyx, corolla, and stamens); they have even investigated the details. The process by which one and the same organ appears in a variety of forms has been called *the metamorphosis of plants*.

5. This metamorphosis appears in three ways: *regular, irregular* and *accidental*.

6. *Regular* metamorphosis may also be called *progressive* metamorphosis: it can be seen to work step by step from the first seed leaves to the last formation of the fruit. By changing one form into another, it ascends—as on a spiritual ladder—to the pinnacle of nature: propagation through two genders. I have observed this carefully for several years, and now propose to explain it in the present essay. Hence, in the following discussion we will consider only the annual plant which progresses continuously from seed to fruiting.

7. *Irregular* metamorphosis might also be called *retrogressive* met-

amorphosis. In the previous case nature pressed forward to her great goal, but here it takes one or more steps backward. There, with irresistible force and tremendous effort, nature formed the flowers and equipped them for works of love;[2] here it seems to grow slack, irresolutely leaving its creation in an indeterminate, malleable state often pleasing to the eye but lacking in inner force and effect. Our observations of this metamorphosis will allow us to discover what is hidden in regular metamorphosis, to see clearly what we can only infer in regular metamorphosis. Thus we hope to attain our goal in the most certain way.

8. We will, however, leave aside the third metamorphosis, caused *accidentally* and from without (especially by insects). It could divert us from the simple path we have to follow, and confuse our purpose. Opportunity may arise elsewhere to speak of these monstrous but rather limited excrescences.

9. I have ventured to develop the present essay without reference to illustrations, although they might seem necessary in some respects. I will reserve their publication until later;[3] this is made easier by the fact that enough material remains for further elucidation and expansion of this short preliminary treatise. Then it will be unnecessary to proceed in the measured tread required by the present work. I will be able to refer to related matters, and several passages gleaned from like-minded writers will be included. In particular, I will be able to use comments from the contemporary masters who grace this noble science. It is to them that I present and dedicate these pages.

I. Of the Seed Leaves

10. Since we intend to observe the successive steps in plant growth, we will begin by directing our attention to the plant as it develops from the seed. At this stage we can easily and clearly recognize the parts belonging to it. Its coverings (which we will not examine for the moment) are left more or less behind in the earth, and in many cases the root establishes itself in the soil before the first organs of its upper growth (already hidden under the seed sheath) emerge to meet the light.

11. These first organs are known as *cotyledons;* they have also been called seed lobes, nuclei, seed laps, and seed leaves in an attempt to characterize the various forms in which we find them.

12. They often appear unformed, filled with a crude material, and as thick as they are broad. Their vessels are unrecognizable and scarcely distinguishable from the substance of the whole; they have little resemblance to a leaf, and we could be misled into considering them separate organs.

13. In many plants, however, they are more like the leaf in form.

They become flatter; their coloration turns greener when they are exposed to light and air; and their vessels become more recognizable, more like the ribs of a leaf.

14. In the end they appear as real leaves: their vessels are capable of the finest development, and their resemblance to the later leaves prevents us from considering them separate organs. Instead, we recognize them as the first leaves of the stem.

15. But a leaf is unthinkable without a node, and a node is unthinkable without an eye. Hence we may infer that the point where the cotyledons are attached is the first true node of the plant. This is confirmed by those plants which produce new eyes directly under the wings of the cotyledons, and develop full branches from these first nodes (as, for example, in *Vicia faba*).[4]

16. The cotyledons are usually double, and here we must make an observation which will become more important later. The leaves of this first node are often paired whereas the later leaves of the stem alternate; i.e., here parts are associated and joined which nature later separates and scatters. Even more noteworthy is the appearance of the cotyledons as a collection of many small leaves around a single axis, and the gradual development of the stem from its center to produce the later leaves singly; this can be seen quite clearly in the growth of the various kinds of pines. Here a circle of needles forms something like a calyx—we will have occasion to remember this when we come to similar phenomena.

17. We will ignore for the moment the quite unformed, individual nuclei of those plants which sprout with but a single leaf.

18. We will, however, note that even the most leaflike cotyledons are always rather undeveloped in comparison to the later leaves of the stem. Their periphery is quite uniform, and we are as little able to detect traces of serration there as we are to find hairs on their surfaces, or other vessels[5] peculiar to more developed leaves.

II. Development of the Stem Leaves from Node to Node

19. Now that the progressive effects of nature are fully visible, we can see the successive development of the leaves clearly. Often one or more of the following leaves were already present in the seed, enclosed between the cotyledons; in their closed state they are known as plumules. In different plants their form varies in relation to that of the cotyledons and the later leaves; most often they differ from the cotyledons simply in being flat, delicate, and generally formed as true leaves. They turn completely green, lie on a visible node, and are undeniably related to the following stem leaves, although they usually lag behind in the development of their periphery, their edge.

20. But further development spreads inexorably from node to node through the leaf: the central rib lengthens, and the side ribs along it reach more or less to the edges. These various relationships between the ribs are the principal cause of the manifold leaf forms. The leaves now appear serrated, deeply notched, or composed of many small leaves (in which case they take the shape of small, perfect branches). The date palm presents a striking example of such successive and pronounced differentiation in the most simple leaf form. In a sequence of several leaves, the central rib advances, the simple fanlike leaf is torn apart, divided, and a highly complex leaf is developed which rivals a branch.

21. The development of the leaf stalk keeps pace with that of the leaf itself, whether the leaf stalk is closely attached to the leaf or forms a separate, small, easily-severed stalk.

22. In various plants we can see that this independent leaf stalk has a tendency to take on the form of a leaf (e.g., in the orange family). Its structure will give rise to certain later observations, but for the moment we will pass them by.

23. Neither can we enter here into further consideration of the stipules; we will simply note in passing that they share in the later transformation of the stalk, particularly when they form a part of it.

24. Although the leaves owe their initial nourishment mainly to the more or less modified watery parts which they draw from the stem, they are indebted to the light and air for the major part of their development and refinement. We found almost no structure and form, or only a coarse one, in those cotyledons produced within the closed seed covering and bloated, as it were, with a crude sap. The leaves of underwater plants likewise show a coarser structure than those of plants exposed to the open air; in fact, a plant growing in low-lying, damp spots will even develop smoother and less refined leaves than it will when transplanted to higher areas, where it will produce rough, hairy, more finely detailed leaves.

25. In the same way, more rarefied gases are very conducive to, if not entirely responsible for, the anastomosis of the vessels which start from the ribs, find one another with their ends, and form the leaf skin. The leaves of many underwater plants are threadlike, or assume the shape of antlers; we are inclined to ascribe this to an incomplete anastomosis. This is shown at a glance by the growth of *Ranunculus aquaticus*,[6] where the leaves produced underwater consist of threadlike ribs, although those developed above water are fully anastomosed and form a connected surface. In fact, we can see the transition clearly in the half-anastomosed, half-threadlike leaves found in this plant.

26. Experiments have shown that the leaves absorb different gases, and combine them with the liquids they contain; there is little doubt that they also return these refined juices to the stem, and thereby help

greatly in the development of the nearby eyes. We have found convincing evidence for this in our analysis of gases developed from the leaves of several plants, *and even from the hollow stems.*[7]

27. In many plants we find that one node arises from another. This is easy to see in stems closed from node to node (like the cereals, grasses, and reeds), but not so easy to see in other plants which are hollow throughout and filled with a pith or rather, a cellular tissue. This substance, previously called *pith,* was considered to occupy an important position among the inner parts of the plant, but its importance has recently been disputed, and with good cause in my opinion (Hedwig, *Leipzig Magazine,* no. 3).[8] Its supposed influence on growth has been flatly denied; the force for growth and reproduction is now ascribed wholly to the inner side of the second bark, the so-called liber. Since the upper node arises from the node below, and receives sap from it, we can easily see that the node above must receive a sap which is finer and more filtered; it must benefit from the effect of the earlier leaves, take on a finer form, and offer its own leaves and eyes even finer juices.[9]

28. *As the coarser liquids are continually drawn off and the purer* ones introduced, as the plant refines its form step by step, it reaches the point ordained by nature. We finally see the leaves in their maximum size and form, and soon note a new phenomenon which tells us that the previous stage is over and the next is at hand, the stage of the flower.

III. Transition to Flowering

29. The transition to flowering may occur quickly or slowly. In the latter case we usually find that the stem leaves begin to grow smaller again, and lose their various external divisions, although they expand somewhat at the base where they join the stem. At the same time we see that the area from node to node on the stem grows more delicate and slender in form; it may even become noticeably longer.

30. It has been found that frequent nourishment hampers the flowering of a plant, whereas scant nourishment accelerates it. This is an even clearer indication of the effect of the stem leaves discussed above. As long as it remains necessary to draw off coarser juices, the potential organs of the plant must continue to develop as instruments for this need. With excessive nourishment this process must be repeated over and over; flowering is rendered impossible, as it were. When the plant is deprived of nourishment, nature can affect it more quickly and easily: the organs of the nodes[10] are refined, the uncontaminated juices work with greater purity and strength, the transformation of the parts becomes possible, and the process takes place unhindered.

IV. Formation of the Calyx

31. We often find this transformation occurring rapidly. In this case the stem, suddenly lengthened and refined, shoots up from the node of the last fully formed leaf and collects several leaves around the axis at its end.

32. The leaves of the calyx are the same organs which appeared previously as the leaves of the stem; now, however, they are collected around a common center, and often have a very different form. This can be demonstrated in the clearest possible way.

33. We already noted a similar effect of nature in our discussion of the cotyledon, where we found several leaves, and apparently several nodes, gathered together around one point. As the various species of pine develop from the seed, they display a rayed circle of unmistakable needles which, unlike other cotyledons, are already well developed. Thus in the earliest infancy of this plant we can already see a hint, as it were, of the power of nature which is to produce flowering and fruiting in later years.

34. In several flowers we find unaltered stem leaves collected in a kind of calyx right under the flower. Since they retain their form clearly, we can rely on the mere appearance in this case, and on botanical terminology which calls them *folia floralia* (flower leaves).

35. We must now turn our attention to the instance mentioned above, where the transition to flowering occurs slowly as the stem leaves come together gradually, transform, and gently steal over, as it were, into the calyx. This can be observed quite clearly in the calyxes of the compositae, especially in sunflowers and calendulas.

36. Nature's power to collect several leaves around one axis can create still closer connections, rendering these clustered, modified leaves even less recognizable, for it may merge them wholly or in part by making their edges grow together. The crowded and closely packed leaves touch one another everywhere in their tender state, anastomose through the influence of the highly purified juices now present in the plant, and produce a bell-shaped or (so-called) single-leaf calyx which betrays its composite origins in its more or less deep incisions or divisions. We can see this if we compare a number of deeply incised calyxes with multi-leaved ones, and especially if we examine the calyxes of several compositae. Thus, for example, we will find that a calendula calyx (noted in systematic descriptions as *simple* and *much divided*) actually consists of many leaves grown into one another and over one another, with the additional intrusion, so to speak, of contracted stem leaves (as noted above).

37. In many plants, the arrangement of individual or merged sepals around the axis of the stalk is constant in number and form; this is also

true of the parts which follow. Biological science, which has developed significantly in recent years, has relied heavily on this consistency for its growth, stability, and reputation. The number and formation of these parts is not as constant in other plants, but even this inconsistency has not deceived the sharp eyes of the masters in this science; through exact definition they have sought to impose stricter limits, so to speak, on these aberrations of nature.

38. This, then, is how nature formed the calyx: it collected several leaves (and thus several nodes) around a central point, frequently in a set number and order; elsewhere on the plant these leaves and nodes would have been produced successively and at a distance from one another. If excessive nourishment had hampered flowering, they would have appeared in separate locations and in their original form. Thus, *nature does not create a new organ in the calyx; it merely gathers and modifies the organs we are already familiar with, and thereby comes a step closer to its goal.*

V. Formation of the Corolla

39. We have seen that the calyx is produced by refined juices created gradually in the plant itself. Now it is destined to serve as the organ of a further refinement. Even a simple mechanical explanation of its effect will convince us of this. For how delicate and suited for the finest filtration must be those tightly contracted and crowded vessels we have seen!

40. We can note the transition from the calyx to the corolla in several ways. Although the calyx is usually green like the stem leaves, the color of one or another of its parts often changes at the tip, edge, back, or even on the inner surface of a part where the outer surface remains green. We always find a refinement connected with this coloration. In this way, ambiguous calyxes arise which might equally well be called corollas.

41. In moving up from the seed leaves, we have observed that a great expansion and development occurs in the leaves, especially in their periphery; from here to the calyx, a contraction takes place in their circumference. Now we note that the corolla is produced by another expansion; the petals are usually larger than the sepals. The organs were contracted in the calyx, but now we find that the purer juices, filtered further through the calyx, produce petals which expand in a quite refined form to present us with new, highly differentiated organs. Their fine structure, color, and fragrance would make it impossible to recognize their origin, were we not able to get at nature's secret in several abnormal cases.

42. Within the calyx of a carnation, for example, there is often a second calyx: one part is quite green, with a tendency to form a single-leaf, incised calyx; another part is jagged, with tips and edges transformed into the delicate, expanded, colored, true beginnings of petals. Here we can again recognize the relationship between corolla and calyx.

43. The relationship between the corolla and the stem leaves is also shown in more than one way, for in several plants the stem leaves show some color long before the plant approaches flowering; others take on full coloration when flowering is near.

44. Sometimes nature skips completely over the organ of the calyx, as it were, and goes directly to the corolla. We then have the opportunity to observe how stem leaves turn into petals. Thus, for example, an almost fully formed and colored petal often appears on tulip stems. It is even more remarkable when half of this leaf is green and attached as part of the stem, while its other, more colorful half rises up as part of the corolla, thereby dividing the leaf in two.

45. It is probable that the color and fragrance of the petals are attributable to the presence of the male germ cell. Apparently it is still insufficiently differentiated in these petals, where it is combined and diluted with other juices. The beautiful appearance of the colors leads us to the notion that the material filling the petals has attained a high degree of purity, but not yet the highest degree (which would appear white and colorless).

VI. Formation of the Stamens

46. This becomes even more probable when we consider the close relationship between the petals and the stamens. Were the relationship between the other parts so striking, well-known, and undeniable, there would be no need for this discourse.

47. Sometimes nature shows us this transition in an orderly way (e.g., in the canna and other plants of this family). A true petal, little changed, contracts at its upper border, and an anther appears, with the rest of the petal serving in place of the filament.

48. In flowers which frequently become double we can observe every step of this transition. Within the fully formed and colored petals of several rose species there appear others which are partly contracted in the middle and partly at the side. This contraction is the result of a small thickened wale which somewhat resembles a perfect anther; the leaf likewise begins to assume the simpler form of a stamen. In some double poppies, fully formed anthers rest on almost unaltered petals in the corolla (which is completely double); in others, the petals are more or less contracted by antherlike wales.

49. If all the stamens are transformed into petals, the flowers will be seedless; but if stamens develop even when a flower becomes double, fructification may occur.

50. Thus a stamen arises when the organs, which earlier expanded as petals, reappear in a highly contracted and refined state. This reaffirms the observation made above: we are made even more aware of the alternating effects of contraction and expansion by which nature finally attains its goal.

VII. Nectaries

51. However rapid the transition from corolla to stamens in many plants, we nonetheless find that nature cannot always achieve this in a single step. Instead, it produces intermediate agents which sometimes resemble the one part in form and purpose, and sometimes the other. Although they take on quite different forms, almost all may be subsumed under one concept: they are gradual transitions from the petals to the stamens.

52. Most of these variously formed organs (which Linnaeus[11] calls nectaries) may be subsumed under this concept. Here we are again bound to admire the intelligence of that extraordinary man: without any clear understanding of their purpose, he followed his intuition and ventured to use one name for such seemingly different organs.

53. Some petals show their relationship to the stamens without any perceptible change in form: they contain tiny cavities or glands which secrete a honeylike juice. In the light of our previous discussion, we may infer that this is an undeveloped and incompletely differentiated fluid of fertilization; our inference will be further justified in the discussion to follow.

54. The so-called nectaries may also appear as independent parts; these sometimes resemble the petals in form, and sometimes the stamens. Thus, for example, the thirteen filaments (each with a tiny red ball) on the nectaries of *Parnassia* have a striking resemblance to stamens. Other nectaries appear as stamens without anthers (as in *Vallisneria* or *Fevillea*); in *Pentapetes* we also find them, in leaf form, alternating with the stamens in a whorl; in addition, systematic descriptions describe them as *filamenta castrata petaliformia*.[12] We find equally unclear formations in *Kiggelaria* and the passion flower.

55. The word *nectary* (in the sense indicated above) seems equally applicable to the distinctive secondary corolla: The formation of petals occurs by expansion, but secondary corollas are formed by contraction (i.e., in the same way as the stamens). Within full, expanded corollas we therefore find small, contracted secondary corollas, as in the narcissus, *Nerium*, and *Agrostemma*.

56. We see even more striking and remarkable changes in the leaves of other species. At the base of the leaf in some flowers we find a small hollow filled with a honeylike juice. This little cavity is deeper in other species and types; it creates a projection shaped like a spur or horn on the back of the leaf, thus producing an immediate modification in the form of the rest of the leaf. We can observe this clearly in different types and varieties of the columbine.

57. This organ is most transformed in the aconite and *Nigella*, for example, but even here its resemblance to the leaf is not hard to see. In *Nigella*, especially, it has a tendency to form again as a leaf, and the flower becomes double with the transformation of the nectaries. Careful examination of the aconite will show the similarity between the nectaries and the arched leaf under which they are hidden.

58. We said above that the nectaries are transitional forms in the change from petal to stamen. Here we can make a few observations about irregular flowers. Thus, for example, the five outer leaves of *Melianthus* might be called true petals, but the five inner leaves could be described as a secondary corolla[13] consisting of six nectaries; the upper nectary is closest to the leaf in form, while the lower one (now called a nectary) is least like the leaf. In the same sense, we might say that the carina of the papilionaceous flowers is a nectary: of all the flower's leaves, it most resembles the stamens in form, and is quite unlike the leaf form of the so-called vexilla.[14] This also explains the brushlike appendages attached to the end of the carina in some species of *Polygala*, and thus it gives us a clear idea of the purpose these parts serve.

59. It should be unnecessary to state here that these remarks are not intended to confuse the distinctions and classifications made by earlier observers and taxonomists. Our only purpose is to help explain variations in plant form.

VIII. Further Remarks on the Stamens

60. Microscopic examination has shown beyond a doubt that the plant's reproductive organs are brought forth by spiral vessels,[15] as are the other organs. We will use this to support the argument that the different plant parts with their apparent variety of forms are nonetheless identical in their inner essence.

61. The spiral vessels lie amid the bundles of sap vessels, and are enclosed by them. We can better understand the strong force of contraction mentioned earlier if we think of the spiral vessels (which really seem like elastic springs) as extremely strong, so that they predominate over the expansive force of the sap vessels.

62. Now the shortened vessel bundles can no longer expand, join

one another, or form a network by anastomosis; the tubular vessels which usually fill the interstices of the network can no longer develop, and there is nothing left to cause the expansion of stem leaves, sepals, and petals; thus a frail, very simple filament arises.

63. The fine membranes of the anther are barely formed, and the extremely delicate vessels terminate between them. Previously the vessels grew longer, expanded, and joined one another, but now we will assume that these same vessels are in a highly contracted state. We see a fully formed pollen emerge from them; in its activity this pollen replaces the expansive force taken from the vessels which produced it. Now released, it seeks out the female parts which the same effect of nature brings to meet it; it attaches itself to these parts, and suffuses them with its influence. Thus we are inclined to say that the union of the two genders is anastomosis on a spiritual level; we do so in the belief that, at least for a moment, this brings the concepts of growth and reproduction closer together.

64. The fine matter developed in the anthers looks like a powder, but these tiny grains of pollen are just vessels containing a highly refined juice. We therefore subscribe to the view that this juice is absorbed by the pistils to which the pollen grains cling, thereby causing fructification. This is made even more likely by the fact that some plants produce no pollen, but only a liquid.

65. Here we recall the honeylike juice of the nectaries, and its probable relationship to the fully developed liquid of the pollen grains. Perhaps the nectaries prepare the way; perhaps their honeylike liquid is absorbed by the pollen grains, and then further differentiated and developed. This opinion is made more plausible by the fact that this juice can no longer be seen after fructification.

66. We will not forget to mention in passing that the filaments grow together in a variety of ways, as do the anthers. They offer the most wonderful examples of what we have often discussed: the anastomosis and union of plant parts which were, at first, strictly separate.

IX. Formation of the Style

67. Earlier I tried to make as clear as possible that the various plant parts developed in sequence are intrinsically identical despite their manifold differences in outer form. It should come as no surprise that I also intend to explain the structure of the female parts in the same way.

68. We will first examine the style apart from the fruit (as often found in nature). This will be all the easier since it is distinct from the fruit in this form.

69. We observe, then, that the style is at the same stage of growth as the stamens. We noted that the stamens are produced by a contraction; this is also true of the styles, and we find that they are either the same size as the stamens, or only a little longer or shorter in form. In many instances the style looks almost like a filament without anthers; the two resemble one another in external form more than any of the other parts. Since both are produced by spiral vessels, we can see plainly that the female part is no more a separate organ than the male part. When our observation has given us a clearer picture of the precise relationship between the female and male parts, we will find that the idea of calling their union an anastomosis becomes even more appropriate and instructive.

70. We often find the style composed of several individual styles which have grown together; its parts are scarcely distinguishable at the tip, and sometimes not even separate. This is the most likely stage for this merger to occur; we have often mentioned its effects. Indeed, it must occur because the delicate, partially developed parts are crowded together in the center of the blossom, where they can coalesce.

71. In various cases of regular metamorphosis, nature gives a more or less clear indication of the close relationship between the style and the previous parts of the blossom. Thus, for instance, the pistil of the iris, with its stigma, appears in the full form of a flower leaf. The umbrella-shaped stigma of *Sarracenia* shows (although not so clearly) that it is composed of several leaves, and even the green color remains. With the aid of the microscope we will find the stigma of several flowers formed as full single-leaved or multi-leaved calyxes (e.g., the crocus; or *Zannichellia*).

72. In retrogressive metamorphosis nature frequently shows us instances where it changes the styles and stigmas back into flower leaves. *Ranunculus asiaticus*, for example, becomes double by transforming the stigmas and pistils of the fruit vessel into true petals, while the anthers just behind the corolla are often unchanged. Several other noteworthy cases will be discussed later.

73. Here we will repeat our earlier observation that the style and the stamens are at the same stage of growth; this offers further evidence for the basic principle of alternation in expansion and contraction. We first noted an expansion from the seed to the fullest development of the stem leaf; then we saw the calyx appear through a contraction, the flower leaves through an expansion, and the reproductive parts through a contraction. We will soon observe the greatest expansion in the fruit, and the greatest concentration in the seed. In these six steps nature steadfastly does its eternal work of propagating vegetation by two genders.

X. Of the Fruits

74. Now we come to the fruits. We will soon realize that these have the same origin as the other parts, and are subject to the same laws. Here we are actually speaking of the capsules formed by nature to enclose the so-called covered seeds, or, more precisely, to develop a small or large number of seeds by fructification within these capsules. It will not require much to show that these containers may also be explained through the nature and structure of the parts discussed earlier.

75. Retrogressive metamorphosis again makes us aware of this natural law. Thus, for example, in the pinks—these flowers known and loved for their irregularity—we often find that the seed capsules are changed back into leaves resembling those in the calyx, and the styles are accordingly shortened. There are even pinks in which the fruit capsule is completely transformed into a true calyx. The divisions at the tips of the calyx still bear delicate remnants of the styles and stigmas; a more or less full corolla develops instead of seeds from the very center of this second calyx.

76. Even in regular and constant formations, nature has many ways of revealing the fruitfulness hidden in a leaf. Thus an altered but still-recognizable leaf of the European linden produces a small stalk from its midrib, and grows a complete flower and fruit on this stalk. The disposition of blossoms and fruits on the leaves of *Ruscus* is even more remarkable.

77. In the ferns we see still stronger—we might even say enormous—evidence of the sheer fruitfulness inherent in the stem leaves: these develop and scatter innumerable seeds (or rather, germs) through an inner impulse, and probably without any well-defined action by two genders. Here the fruitfulness of a single leaf rivals that of a wide-spreading plant, or even a large tree with its many branches.

78. With these observations in mind, we will not fail to recognize the leaf form in seed vessels—regardless of their manifold formations, their particular purpose and context. Thus, for example, the pod may be viewed as a single, folded leaf with its edges grown together; husks, as consisting of leaves grown more over one another; and compound capsules may be understood as several leaves united round a central point, with their inner sides open toward one another and their edges joined. We can see this for ourselves when these compound capsules burst apart after maturation, for each part will then present itself as an open pod or husk. We may also observe a similar process taking place regularly in different species of the same genus: the fruit capsules of *Nigella orientalis*, for instance, are partially merged pods grouped around an axis; but in *Nigella damascena* they are fully merged.

79. Nature masks the resemblance to the leaf mainly by forming soft, juicy seed vessels, or hard, woody ones. But this similarity will not

escape our attention if we know how to follow it carefully through all its transitions. Here we will have to be content with having given a description of the general concept along with several examples of nature's consistent behavior. The great variety in seed capsules will provide material for a great many other observations in the future.

80. The relationship between the seed capsules and the previous parts also appears in the stigma, situated right on top of the seed capsule and inseparably joined to it. We have already demonstrated the relationship of the stigma to the leaf form, and here we may note it again: in double poppies we find that the stigmas of the seed capsules are changed into delicate, colored leaflets which look exactly like petals.

81. The last and most pronounced expansion in the growth of the plant appears in the fruit. This expansion is often very great—even enormous—in inner force as well as outer form. Since it usually occurs after fertilization, it seems likely that as the developing seed draws juices from the entire plant for its growth, the flow of these juices is directed into the seed capsule. The vessels of the seed capsule are thereby nourished and expanded, often becoming extremely gorged and swollen. It can be inferred from our earlier discussion that purer gases play a part in this, an inference supported by the discovery that the distended pods of *Colutea* contain a pure gas.[16]

XI. Of the Coverings Lying Next to the Seed

82. *By way of contrast, the seed is in the most extreme state of contraction* and inner development. In various plants we can observe that the seed transforms leaves into an outer covering, adapts them more or less to its shape, and often has the power to annex them fully, completely changing their form. We saw above that many seeds can develop in and from a single leaf; hence it will come as no surprise to find a single embryo clothed in a leaf covering.

83. We can see the traces of such incompletely adapted leaf forms in many winged seeds (e.g., the maple, the elm, the ash, and the birch). The calendula's three distinct rings of differently formed seeds offer a remarkable example of how the embryo pulls broad coverings together, gradually adapting them to its shape. The outer ring is still related to the petals in form, except that a rudimentary seed swells the rib, causing a fold in the leaf; a small membrane also runs lengthwise along the inside of the crease, dividing the leaf in two. The next ring shows further changes: the broad form of the leaf has entirely disappeared, along with the membrane; but its shape is somewhat less elongated, while the rudimentary seed on the back has become more visible, and the small raised spots on the seed have grown more distinct. These two rows appear to be either unfructified or only partially fructified. They are

followed by a third row of seeds in their true form: strongly curved, and with a tightly fitted involucre which is fully developed in all its ridges and raised portions. Here we again see a powerful contraction of broad, leaflike parts, a contraction produced by the inner power of the seed, just as we earlier saw the flower leaf contracted by the power of the anthers.

XII. Review and Transition

84. Thus we have sought to follow as carefully as possible in the footsteps of nature. We have accompanied the outer form of the plant through all its transformations, from the seed to the formation of a new seed; we have investigated the outer expression of the forces by which the plant gradually transforms one and the same organ, but without any pretense of uncovering the basic impulses behind the natural phenomena. So as not to lose the thread which guides us, we have limited our discussion entirely to annual plants; we have noted only the transformation of the leaves accompanying the nodes, and have derived all the forms from them. But to lend our discussion the required thoroughness, we must now speak of the eyes hidden beneath each leaf; under certain circumstances these develop, and under others they seem to disappear entirely.

XIII. Of the Eyes and their Development

85. Nature has given each node the power to produce one or more eyes; this process takes place near its companion leaves, which seem to prepare the way for the formation and growth of the eyes, and help in their production.

86. The primary, simple, slow process of plant reproduction is based on the successive development of one node from the other, and the growth of an eye close to it.

87. We know that such an eye is similar to the ripe seed in its effect; in fact, we can often recognize the whole shape of the potential plant more easily in the eye than in the seed.

88. Although the root point[17] is hard to find in the eye, it is just as much there as in the seed, and will develop quickly and easily, especially in the presence of moisture.

89. The eye needs no cotyledon because it is connected to the fully-developed parent plant, and receives adequate nourishment as long as the connection remains. Once separated, it will draw nourishment from the plant to which it is grafted, or from the roots developed as soon as a branch is planted in the earth.

90. The eye consists of more or less developed nodes and leaves which have the task of enhancing the future growth of the plant. Thus the side branches growing from the nodes of the plant may be considered separate small plants placed on the parent in the same way that the parent is attached to the earth.

91. The two have often been compared and contrasted, most recently in such an intelligent and exact way that we will simply refer to it here with our unqualified admiration (Gaertner, *De fructibus et seminibus plantarum,* Chapt. I).[18]

92. We will say only the following on this point. Nature makes a clear distinction between eyes and seeds in plants with a highly differentiated structure. But if we descend to plants with a less differentiated structure, the two become indistinguishable, even for the sharpest observer. There are seeds which are clearly seeds, and gemmae which are clearly gemmae,[19] but it takes an act of reason rather than observation to find the connection between the seeds, which are actually fertilized and separated from the parent plant by the reproductive process, and the gemmae, which simply grow out of the plant and detach without apparent cause.

93. With this in mind, we may conclude that the seeds are closely related to the eyes and gemmae, although they differ from the eyes in being enclosed, and from the gemmae in having a perceptible cause for their formation and separation.

XIV. Formation of Composite Flowers and Fruits

94. Thus far we have focused on the transformation of nodal leaves in our attempt to explain the development of simple flowers, as well as the production of seeds enclosed in capsules. Closer examination will show that no eyes form in these cases, and moreover, that the formation of such eyes is utterly impossible. We must look to the formation of eyes, however, to explain the development of composite flowers or compound fruit arranged around a single cone, a single spindle, a single disk, etc.

95. Certain stems do not gradually prepare the way for a single flower by saving their energies; instead, they produce their flowers directly from the nodes, and frequently continue this process without interruption to their very tip. This phenomenon may be explained, however, through the theory presented earlier. All flowers developed from the eyes must be considered whole plants situated on the parent, just as the parent is situated on the earth. Since they now receive purer juices from the nodes, even the first leaves of the tiny twig appear much more fully developed that the first leaves (following the cotyledons) of the

parent; in fact, it is often possible to develop the calyx and flower immediately.

96. With an increase in nourishment, the flowers developed from the eyes would become twigs; they are necessarily subject to the same conditions as the parent stem, and share in its fate.

97. As these flowers develop from node to node, we also find that the stem leaves undergo the same changes seen previously in the gradual transition to the calyx. They contract more and more, finally disappearing almost completely, and they are called bracts when their form has become somewhat different from a leaf. The stem likewise grows thinner, the nodes crowd closer together, and all the phenomena noted earlier take place, but there is no decisive formation of a flower at the end of the stem because nature has already exercised its rights from node to node.

98. Having examined the stem adorned with a flower at every node, we will soon arrive at an explanation of the *composite flower*, especially if we recall what was said before about the creation of the calyx.

99. Nature forms a composite calyx out of many leaves compacted around a single axis. Driven by the same strong growth impulse, it suddenly develops an endless stem, so to speak, with all its eyes in the form of flowers and compacted as much as possible; each small flower fertilizes the seed vessel standing ready below. The nodal leaves are not always lost in this enormous contraction; in the thistles, the little leaves faithfully accompany the floret developed from the eye next to them (compare the form of *Dipsacus laciniatus*). In many grasses, each flower is accompanied by such a little leaf (called a glume).

100. Thus we now realize that the seeds developed around a composite flower are true eyes created and formed by the reproductive process. With this concept firmly in mind, we may compare a variety of plants, their growth and their fruits, and find convincing evidence in what we see.

101. Hence, it will not be hard to explain the covered or uncovered seeds produced in the center of a single flower, often in a group around a spindle. For it is all the same, whether a single flower surrounds a common ovary where the merged pistils absorb the reproductive juices from the flower's anthers and infuse them into the ovules, or whether each ovule has its own pistil, its own anthers, and its own petals around it.

102. We are convinced that with a little practice the observer will find it easy to explain the various forms of flowers and fruits in this way. To do so, however, requires that he feel as comfortable working with the principles established above—expansion and contraction, compaction and anastomosis—as he would with algebraic formulas. Here it is crucial that we thoroughly observe and compare the different

stages nature goes through in the formation of genera, species, and varieties, as well as in the growth of each individual plant. For this reason alone, it would be both pleasant and useful to have a collection of properly arranged illustrations labeled with the botanical terms for the different parts of the plant. In connection with the above theory, two kinds of proliferous flowers would serve as especially useful illustrations.

XV. Proliferous Rose

103. The proliferous rose (see frontispiece) offers a very clear example of everything we sought earlier through our power of imagination and understanding. The calyx and corolla are arranged and developed around the axis, but the seed vessel is not contracted in the center with the male and female organs arranged around it. Instead, the stem, half reddish and half greenish, continues to grow, developing a succession of small, dark red, folded petals, some of which bear traces of anthers. The stem grows further; thorns reappear on it; one by one, the colored leaves which follow become smaller; and finally we see them turn into stem leaves, partly red and partly green. A series of regular nodes forms, and from their eyes small but imperfect rosebuds once again appear.

104. This example also gives visible evidence of another point made earlier; i.e., that all calyxes are only contracted *folia floralia*.[20] Here the regular calyx gathered around the axis consists of five fully developed, compound leaves with three or five leaflets, the same sort of leaf usually produced by rose branches at their nodes.

XVI. Proliferous Carnation

105. After spending some time with this phenomenon, we may turn to another which is still more remarkable: the proliferous carnation. We see a perfect flower equipped with a calyx as well as a double corolla and completed in the center with a seed capsule, although this is not fully developed. Four perfect new flowers develop from the sides of the corolla; these are separated from the parent flower by stalks having three or more nodes. They have their own calyxes, and double corollas formed not so much by individual leaves as by leaf crowns merged at the base, or more often by flower leaves which have grown together like little twigs around a stem. Despite this extreme development, filaments and anthers are found in some. We see fruit capsules with styles, and seed receptacles which have grown back into leaves; in one such flower the seed envelopes had joined to create a full calyx containing the rudiments of another perfect double flower.

106. In the rose we have seen a partially defined flower, as it were, with a stem growing again from its center, and new leaves developing on this stem. But in this carnation, with its well-formed calyx, perfect corolla, and true seed capsules in the center, we find that eyes develop from the circle of petals, producing real branches and blossoms. Thus both instances illustrate that nature usually stops the growth process at the flower and closes the account there, so to speak; nature precludes the possibility of growth in endless stages, for it wants to hasten toward its goal by forming seeds.

XVII. Linnaeus' Theory of Anticipation

107. If I have stumbled here and there on the path which a predecessor described as terrifying and dangerous, even though he attempted it under the guidance of his great teacher (Ferber, *Diss. de prolepsi plantarum*);[21] if I have not done enough to pave the way for those who follow; if I have not cleared every obstacle from the path—nonetheless, I hope that this effort will not prove altogether fruitless.

108. It is now time to consider a theory proposed by Linnaeus to explain these phenomena.[22] The things discussed here could not have escaped his sharp eyes; if we have made progress where he faltered, it is only because of a concerted effort by other observers and thinkers to clear the way and eliminate prejudice. A full comparison between his theory and the above discussion would be too time-consuming here. The knowledgeable reader can make the comparison himself, but it would require too much detailed explanation to clarify it here for those who have not yet studied these things.

109. He started with an observation of trees, those complex and long-lived plants. He observed that a tree planted in a wide pot and over-fertilized would produce branch after branch for several years, while the same tree in a smaller pot would quickly bear blossoms and fruits. He saw that the successive development of the first tree was suddenly compressed in the second. He called this effect of nature *prolepsis* (anticipation) since the plant seemed to anticipate six years' growth in the six steps noted above.[23] He therefore developed his theory from tree buds; he did not pay much attention to annual plants, for he could see that these did not fit his theory as well. His theory would have us assume that nature really intended every annual plant to grow for six years, but the plant forestalled this maturation period by quickly blossoming, bearing fruit, and then dying.

110. We, however, began by following the growth of annual plants. Our approach is readily applicable to longer-lived plants, for a bud opening on the oldest tree may be considered an annual plant even

though it develops on a long-existent stem and may itself last for a longer time.

111. There was a second reason for Linnaeus' lack of progress: he mistakenly viewed the various concentric parts of the plant (the outer bark,[24] the inner bark, the wood, the pith) as similar in their effect, similar in the way they participated in the life of the plant. He identified the various rings of the stem as the source of blossom and fruit because the latter, like the former, enclose one another and develop out of one another. But this was merely a superficial observation which closer examination shows to be false. The outer bark is unsuited to yield anything further; in the long-lived tree it is too separate and too hardened on the outside, just as the wood becomes too hard on the inside. In many trees the outer bark drops away, and in others it can be peeled without causing damage; thus it produces neither calyx nor any other living part of the tree. It is the second bark that contains all the power of life and growth; to the extent it is damaged, the tree's growth is also hindered. After examining all the external parts of the tree, we will discover that this is the part which brings growth gradually in the stem, and quickly in the flower and fruit. Linnaeus assigned it the mere secondary task of producing petals. By contrast, he assigned to the wood the important job of producing stamens, although we can see that the wood is rendered inactive by its solidity; it is durable but too dead to produce life. He supposed the pith to have the most important function: production of the pistils and numerous offspring. Yet doubts about the great importance of the pith seem to me significant and conclusive, as do the reasons for raising them.[25] The style and fruit merely appear to develop from the pith because our first impression is of soft, ill-defined, pithlike, parenchymatous formations gathered together in the center of the stem where we usually see only the pith.

XVIII. Recapitulation

112. I hope that this attempt to explain the metamorphosis of plants may contribute something to the resolution of these doubts, and lead to further findings and conclusions. The observations which serve as the basis for my work were made at various times, and have already been collected and organized (Batsch, *Introduction to the Identification and History of Plants*, Part I, Chapt. 19).[26] It should not be long before we discover whether the step taken here brings us any closer to the truth. We will summarize the principal results of the foregoing treatise as briefly as possible.

113. If we consider the plant in terms of how it expresses its vitality, we will discover that this occurs in two ways: first, through growth

(production of stem and leaves); and secondly, through reproduction (culminating in the formation of flower and fruit). If we examine this growth more closely, we will find that as the plant continues from node to node, growing vegetatively from leaf to leaf, a kind of reproduction also takes place, but a reproduction unlike that of flower and fruit; whereas the latter occurs all at once, the former is successive and appears as a sequence of individual developments. The power shown in gradual vegetative growth is closely related to the power suddenly displayed in major reproduction. Under certain circumstances a plant can be made to continue its vegetative growth, and under others the production of flowers can be forced. The former occurs when cruder juices accumulate; the latter, when more rarefied juices predominate.

114. In saying that vegetative growth is successive reproduction, while flowering and fruiting are simultaneous reproduction, we are also describing how each occurs. A vegetating plant expands to some extent, developing a stalk or stem; the intervals between nodes are usually perceptible, and its leaves spread out on all sides. A blossoming plant, on the other hand, shows a contraction of all its parts; the dimensions of length and breadth are canceled out, as it were; all its organs develop in a highly concentrated state and lie next to one another.

115. Whether the plant grows vegetatively, or flowers and bears fruit, the same organs fulfill nature's laws throughout, although with different functions and often under different guises. The organ which expanded on the stem as a leaf, assuming a variety of forms, is the same organ which now contracts in the calyx, expands again in the petal, contracts in the reproductive apparatus, only to expand finally as the fruit.

116. This effect of nature is accompanied by another: the gathering of different organs in set numbers and proportions around a common center. Under certain conditions, however, some flowers far exceed these proportions, or vary them in other ways.

117. Anastomosis also plays a part in the formation of flowers and fruits; the extremely crowded and delicate organs of fructification are merged during the whole of their existence, or at least some part of it.

118. The phenomena of convergence, centering, and anastomosis are not peculiar to flower and fruit alone. We can discover something similar in the cotyledons, and ample material will be found in other parts of the plant for further observations of this sort.

119. We have sought to derive the apparently different organs of the vegetating and flowering plant from one organ; i.e., the leaf normally developed at each node. We have likewise ventured to find in the leaf form a source for the fruits which completely cover their seed.

120. Here we would obviously need a general term to describe this organ which metamorphosed into such a variety of forms, a term descriptive of the standard against which to compare the various mani-

festations of its form.[27] For the present, however, we must be satisfied with learning to relate these manifestations both forward and backward. Thus we can say that a stamen is a contracted petal or, with equal justification, that a petal is a stamen in a state of expansion; that a sepal is a contracted stem leaf with a certain degree of refinement, or that a stem leaf is a sepal expanded by an influx of cruder juices.

121. We might likewise say of the stem that it is an expanded flower and fruit, just as we assumed that the flower and fruit are a contracted stem.

122. At the conclusion of the treatise I also took the development of eyes into account, and attempted thereby to explain composite flowers as well as uncovered fruits.

123. Thus I have tried to be as clear and thorough as I could in presenting a view I find rather convincing. Nonetheless, the evidence may still seem insufficient, objections may still arise, and my explanations may sometimes not seem pertinent. I will be all the more careful to note any suggestions in the future, and will discuss this material in a more precise and detailed way so that my point of view becomes clearer; perhaps then it will be more deserving of applause than at present.

An Unreasonable Demand

I have been reproached with failing to take account of the root in my work on the metamorphosis of plants. When I heard of this, I thought it strange that I was supposed to have done something forty years ago which no one is doing today. I have as much respect for the root as I have for the foundations of the Strasbourg and Cologne cathedrals,[1] and am not entirely unacquainted with these foundations, for I possessed a drawing of excavations made some years ago in the minster grounds; I later passed this on to my friend Boisserée as something of interest to him.[2] In contemplating a building, however, we actually begin at ground level, and use the term *ground plan* for the basic outline of the building which then soars aloft in a variety of forms. The deeper level, from which the higher level rises skyward, is left to the reason, judgment, and conscience of the architect. We, however, naturally infer the soundness of the substructure from the quality and consistency of the building.

So, too, with the root: it really didn't concern me. What was I to do with a formation of filaments, fibers, bulbs, and tubers; one so limited as to yield only an unpleasant assortment, an endless variety with never an intensification? After all, the phenomenon of intensification was what attracted me in my pursuit of this profession—it alone captivated me, it alone carried me along.[3] But we should all pursue our course in a balanced way; may others have the pleasure of looking back modestly on forty years' work,[4] just as some beneficent guiding spirit has helped us to do.

Weimar
June 27, 1824

Leaf and Root[1]

Leaf and root are related, for both belong to the higher structure of the plant. In the developed plant, however, this is not so obvious since the leaf grows above ground and the root grows underground; i.e., the two seem fundamentally separate. But the phenomenon of aerial roots shows us that nature has also endowed the trunk and stem with the ability to produce such things. Just a few observations will further clarify this point.

1) Perceptive researchers have already applied the word *root* to the lateral fibers connecting the leaves to the trunk and stem beneath them; thus they develop and nourish themselves by sharing in the life of the sapwood. Further investigation will show that it is not just our power of imagination which finds similarities here, but our understanding which discovers real analogies.

2) In our thought, however, leaf and eye are inseparable: every leaf has an eye behind it, every eye has leaves which overlap like scales, and each of these leaves (the first as well as those that follow) gives us a picture of the whole plant. As a result, we must think of any point on the plant as a root point with the potential to produce a root.[2]

3) Some years ago I heard that, with care, a bulb leaf could be removed from the small, garden variety *Fritillaria*[3] and dried between blotting paper (as for an herbarium); after a time it would develop tiny bulbs along the bottom, and these could be replanted. I remember having experimented with this myself, but I don't recall what happened—it would be easy to repeat the experiment and obtain the results.

4) Chief Forester von Fritsch[4] recently sent a remarkable example of root development for our collection. After an old European linden tree was cut down because of rot at its core, an upper limb was found to have sunk deep roots in this rot, and the limb continued to thrive as if planted in the earth. I would explain this matter as follows. Earlier the tree had lost part of its crown (always the result of such decay), and a root point developed from a newly sprouted twig; the root quickly

found nourishment in the moist, decaying surface of the old tree, and continued to grow, drawing nourishment from the rotting core, and helping spread the rot.

The innumerable twigs covering an old linden trunk from the root up show how rich the tree is in new shoots. The question is whether skillful handling might not force some of these young shoots to put down roots.

5) Propagation by cuttings, a common practice in our day, also shows that the root is present everywhere.

Weimar
March 20, 1825

J. W. v. Goethe

Remarkable Healing of a Severely Damaged Tree

Thick, tall rowan[1] trees have stood from time immemorial in the forecourt of the Chief Forester's house in Ilmenau.[2] These trees began to die at the beginning of the century, and it was ordered that they be cut down. Unfortunately, the woodcutters also put their saws to a healthy tree; this tree was cut two thirds of the way through before they were told to stop, whereupon the damaged spot was covered over, bound up, and made airtight. The tree stood another twenty years, but then its outer branches began to die; last fall it broke off at the roots in a storm.

Chief Forester von Fritsch[3] has been so thoughtful as to provide us with a section twelve inches high which clearly shows the earlier cut in the center. This cut left a depressed scar, but it healed over so well that the storm did no harm to the healed spot.

We might think of this tree as grafted onto itself. Care was taken to make the wound airtight after the saw was pulled out; thus there was an immediate resumption of life in the thin bark and the sapwood under it, and they continued to grow.

But not in the heartwood; once cut, it was unable to grow together again. The stagnating sap decomposed, and the core, normally so solid, began to suffer from a kind of rot.

It is also interesting that the healed sapwood formed no additional heartwood, and thus the rot extends two thirds of the way into the core.

This is not so in the healthy third; it seems to have continued growing, giving the trunk an oval shape. The short diameter (across the center of the annual rings) measures 15 inches, while the long diameter measures 18 inches, 5 of which seem to be healthy wood.

Bignonia radicans[1]

In September, 1786, I visited the Padua botanical garden[2] where I saw a broad, high wall thickly covered with *Bignonia radicans;* the clusters of deep yellow, chalice-like flowers hung down in inexpressible profusion. This so impressed me that I grew especially fond of this flower, and always gave it my attention when I found it growing in botanical gardens (in the Weimar gardens, where it was particularly cultivated, and in my own garden as well).

It is a creeping plant with an apparent proclivity for endless growth, but it lacks the organs for attaching itself, clinging, or gripping. We therefore force it to climb by tying it to latticework; this keeps it upright and allows it to climb quite high.

I had always seen this method used, and I used it in my own plantings. But I was dismayed to find the new shoots growing against the wall behind the lattice, forcing their way between the lattice and the wall; this had the somewhat unpleasant effect of trapping the beautiful clusters of flowers in a cramped space, thus depriving the viewer of the pleasure they might bring, for they should be admired as hanging flowers. After many observations and experiments, I finally discovered the following.

Looking at a branch of the *Bignonia,* I find unevenly pinnated leaves growing from it in pairs, and below the leaves on the back there are glandlike growths which look somewhat like a bunch of grapes when viewed under weak magnification. The three rows of tiny berries or beads descending in the center have about fifteen such growths, and the adjacent rows have fewer—hence the grapelike appearance. Two such organs are located next to one another on the back, below the leaf pair at each node (as mentioned earlier). At their earliest stage, the beads of these tiny bunches of "grapes" are clear and fine (although I only observed this once, at the end of August, 1828; next spring I shall take care to examine this phenomenon more closely). I immersed them in alcohol, where they retained their form but took on a brown color.

In any case, this organ frequently has a corky appearance: brownish,

dry, about one line high,[3] comblike or bristlelike. It might be taken for a useless, even harmful, growth. On the whole, this organ varies in form: it lengthens along the stem, stands alone in small clusters, loses itself in recesses, or is replaced by small dimples which penetrate to the wood. I found one such group in the form of a large cluster nine lines long; it branched like a true root, and under the microscope its delicate filaments were seen to possess fine hairs.

We might ask if these spots could not put out real roots under the right conditions. At least we cannot help thinking that these organs are moisture collectors apparently required by creeping perennials as they spread far from the point where they are rooted in the ground.

Very few young shoots of a *Bignonia* trained high up on a building showed any trace of this organ, but these organs were found on many nodes in a shoot from a shrublike plant, hardly an ell high,[4] which grew in a poor, damp location with little sun. This illustrates a mutual relationship: the organ is called forth by the moisture which, in turn, is supplied to the plant by the organ.

Thus I said to myself: this is a creeping plant, not meant to climb, but to hang. We take the wrong approach when we force it to grow upwards, where it is deprived of its most essential nourishment. We can grow it to a certain height, but then we should let it cascade down along terraces and rocks if we want to see it at its most beautiful. The youngest shoots will lie with their backs against the damp stone, and absorb enough moisture to sustain their foliage and their thousandfold clusters of flowers. This also places the little shoots in a natural position. Remember that now a shoot grows up against a wall, producing a heavy cluster of flowers so that the shoot finally falls forward and turns its back (where these organs of nourishment are developed) toward the light and the sun. Thus these useful organs are dried up and destroyed just at the moment when the full development of the plant requires their help; the leaves also fall off the shoot, and the flower cluster hangs down from a bare stem, although the shoot ought to be covered with leaves out to the flower.

We can let the grapevine spread and grow wherever we wish, for it knows how to cling anywhere with its tendrils.[5] But we should plant such a strikingly beautiful plant as *Bignonia radicans* in a high spot so that it can grow down. If the spot is sunny, we will see its golden bells hanging in profusion, although past practice has required extra care for this dramatic ornamental plant, and even then the results were not particularly pleasing.

As an afterthought, I should mention that anyone wishing to write about this plant would be gratified to find there are six to eight of these glands located just down by the socket on the individual leaf stalks of the pinnate leaves noted above. A very delicate row of tiny hairs also

appears on the shoots just under or next to the eyes where one node begins and the other ends. Lastly, the shoot is covered with countless tiny white spots in the areas between the nodes. Thus every part of this plant is equipped to get the nourishing moisture it needs from the atmosphere or its surroundings.

Excerpt from "The Spiral Tendency in Vegetation"[1]

When something in our observation of nature takes us aback, when we find our usual way of thought inadequate for its comprehension, we are well advised to look about for parallels in the history of thought and understanding.

Here we were simply reminded of Anaxagoras' homoeomeries,[2] although a man of his day had to be satisfied with explaining a thing only through itself. Supported by empirical observation, however, we might venture to consider such a notion.

We may leave aside the fact that these homoeomeries are applicable mainly to simple primitive phenomena. But on a higher level, we have actually discovered that spiral organs extend throughout the plant in the most minute form, and we are equally sure there is a spiral tendency whereby the plant lives out its life, finally reaching full development.

Thus let us not completely reject Anaxagoras' idea as inadequate, for we should remember that there is always something to what a gifted man can formulate in thought, even though the formulation may be difficult to accept and apply.

In light of this new insight, we will venture to state the following. Having grasped the concept of metamorphosis fully, we may go on to examine the development of the plant in more detail, and will begin by noting a *vertical* tendency. We can think of this as a spiritual staff supporting the plant's existence and maintaining it over long periods of time. This vital principle manifests itself in the longitudinal fibers which yield flexible strands for a variety of uses. It forms the wood in trees and keeps annuals or biennials upright; even in climbing or creeping plants it works to create the extension from node to node.

Thus we must observe the spiral forms which wind about these plants.

The system which rises vertically in the plant produces the enduring element, the solid, the lasting (the fibers in short-lived plants, most of the wood in long-lived ones).

The spiral system is the element that develops, expands, nourishes; as such it is short-lived and different from the vertical. Where its effect predominates, it soon grows weak and begins to decay; where it joins the vertical system, the two grow together to form a lasting unity as wood or some other solid part.

Neither of the two systems can be considered as working alone; they are always and forever together. In complete balance they produce the most perfect development of vegetation.

The spiral system is really the nourishing element through which eye after eye is developed, and we can therefore see that an excess of nourishment will make it predominant over the vertical system. Thus the whole will be robbed of its support, of its skeletal structure, so to speak; it will lose itself in the rush to develop an excessive number of eyes. In tall, fully formed ash trees, for example, I have never found those flattened, twisted branches which look something like crosiers when the effect is pronounced. But I have found them on trees where the top has been lost and the new twigs receive an excess of nourishment from the old trunk.

Other monstrosities (to be discussed later) arise when the vertical growth no longer balances the spiral system, when it is overshadowed by the spiral system. The vertical structure (whether fibrous or woody) is weakened and undermined in such a plant; it is brought to ruin, as it were. But the spiral system (on which eyes and buds depend) is accelerated, the tree branch flattened, the stem of the plant (which lacks wood) is bloated, and its interior destroyed. In the process, the spiral tendency appears, showing itself in twists, turns and curves. Examination of a branch will give us a full and thorough text for interpretation.

The spiral *vessels* have long been recognized, and their existence is freely acknowledged, but we must really think of them as individual organs subordinated to the spiral tendency. They have been sought in all parts of the plant and found almost everywhere, especially in sapwood where they even exhibit certain signs of life. It is quite in keeping with nature that its large-scale intentions are realized in the smallest detail.

As the basic law of life, this spiral tendency must first appear in the development from the seed. We will start with an observation of its appearance in the dicotyledons where the first seed leaves are clearly paired. The pair of cotyledons in these plants is often followed by a second pair of small but more developed leaves arranged crosswise, an arrangement which may continue for a time. But in many such plants it becomes obvious that the leaves growing higher on the stem do not subscribe to this social order, nor do the potential or actual eyes located behind them. One always tries to rush ahead of the other, causing the

strangest placements; when all the parts in such a series finally gather together, the time of fructification in the flower draws near, and the development of the fruit follows.

In the *Calla*[3] the leaf ribs quickly develop into leaf stems, and gradually grow round until they finally appear, completely rounded, as flower stalks. The flower is apparently a leaf end which has lost its green color; its vessels run from socket to periphery without branching, and curve inward around the spike which now represents the vertical position where flowering and fruiting take place.

The vertical tendency expresses itself from the moment of sprouting; it is how the plant takes root in the earth and grows upward at the same time. Perhaps we could observe how long this tendency remains predominant in the growth process, for we might assume it to be entirely responsible for the alternating placement of dicotyledonous leaf pairs at right angles to one another; this may seem problematic, however, since a certain spiral effect in any upward growth is not to be denied. In any case, as recessive as the vertical tendency may become, it reappears in blossoming where it creates the axis for the formation of each flower, manifesting itself most clearly in the spike and the spathe.

Research in plant anatomy has gradually clarified the matter of the spiral vessels found throughout the plant organism, as well as the aberrations in their form. This is not the place to go into detail; the beginning botanist can learn about them from a handbook, and the more advanced observer can turn to one of the larger works, or even look at nature itself.

It has long been thought that these vessels bring life to the plant organism, although their actual effect has not been sufficiently explained.

In our time, researchers have insisted that these vessels themselves should be recognized as alive, and described as such.

An Intermaxillary Bone Is Present in the Upper Jaw of Man As Well As in Animals[1] (Jena, 1786)

Several attempts at osteological illustration are collected here with the intention of introducing students and friends of comparative anatomy to a small discovery I have made.[2]

In the skulls of animals it is easy to see that the upper jaw consists of more than a pair of bones. Its anterior part, joined by clearly visible sutures and harmonies to the posterior parts, forms a pair of separate bones.

The anterior part of the upper jaw has been given the name *os intermaxillare*. Known already to the ancients (Galen, *Liber de ossibus*, chapt. 3),[3] this bone has been the object of recent attention because it is said to be a characteristic which separates ape from man: its presence is admitted in the former, but denied in the latter (Camper, *Collected Shorter Writings*, ed. Herbell, vol. 1, pt. 2, pp. 93-94; Blumenbach, *De varietate generis humani nativa*, p. 33).[4] Were observation not convincing evidence of things in nature, I would be reluctant to appear with my claim that this bone is present in man as well.

I will be as brief as possible, since mere examination and comparison of several skulls offers a quick test of this simple assertion.

The bone under discussion is called the intermaxillary bone because it is inserted between the two main bones of the upper jaw.[5] It, too, is made up of two bones which meet in the middle of the face.

This bone is shaped differently in different animals, and its form varies noticeably depending on whether it protrudes or recedes. The form of the broadest and thickest part at the front (which I have called the corpus) depends on the kind of food allotted the animal by nature, for with this part it must first seize, grip, pluck, chew off, or shred its food—somehow get hold of its nourishment. Thus it may be flat and equipped with cartilages, armed with dull or sharp incisors, or have some other form corresponding to what the animal eats.

A lateral process connects it above with the upper jaw, the nasal bone, and sometimes with the frontal bone.

Inside the first incisor (or the position it would occupy) a spur or

spina extends back, meets the palatine process, and forms a channel into which the lower and anterior part of the *vomer* or plowshare bone is inserted. This spina, the lateral portion of the corpus of this intermediate bone, and the anterior portion of the palatine process in the upper jaw create the canals (*canales incisivi* or *naso-palatini*) through which small blood vessels and nerves of the second division of the trigeminal nerve pass.

Plate I (see plates following page 206) shows these three parts in a horse's skull at a glance:

A. *corpus*
B. *apophysis maxillaris*
C. *apophysis palatina*

We may observe and describe several subdivisions in each of these larger parts. With the help of Councillor Loder[6] I have prepared the Latin nomenclature which is appended here as an aid. It was difficult to make this nomenclature applicable to all animals, for in some animals certain parts recede or merge, while in others they may disappear entirely. Thus this table would certainly be subject to improvement if pursued in more detail.

Os intermaxillare

A. *Corpus*
  a. *Superficies anterior*
    1. *Margo superior in quo Spina nasalis*
    2. *Margo inferior seu alveolaris*
    3. *Angulus inferior exterior corporis*
  b. *Superficies posterior, qua Os intermaxillare jungitur Apophysi palatinae Ossis maxillaris superioris*
  c. *Superficies lateralis exterior, qua Os intermaxillare jungitur Ossi maxillari superiori*
  d. *Superficies lateralis interior, qua alterum Os intermaxillare jungitur alteri*
  e. *Superficies superior*
    Margo anterior, in quo Spina nasalis, vid. I
    4. *Margo posterior sive Ora superior canalis naso-palatini*
  f. *Superficies inferior*
    5. *Pars alveolaris*
    6. *Pars palatina*
    7. *Ora inferior canalis naso-palatini*
B. *Apophysis maxillaris*
  g. *Superficies anterior*
  h. *Superficies lateralis interna*
    8. *Eminentia linearis*
  i. *Superficies lateralis externa*

- k. *Margo exterior*
- l. *Margo interior*
- m. *Margo posterior*
- n. *Angulus apophyseos maxillaris*

C. *Apophysis palatina*

- o. *Extremitas anterior*
- p. *Extremitas posterior*
- q. *Superficies superior*
- r. *Superficies inferior*
- s. *Superficies lateralis interna*
- t. *Superficies lateralis externa*

The letters and numbers of the parts in the above table are also indicated in the sketches and some of the engravings. Here and there it may not be immediately apparent why certain divisions were made or names chosen. None of this was done without cause; the difficulty noted above will be even more evident if several skulls are examined and compared.

I will now proceed to a brief review of the plates. The clarity and consistency of these engravings will spare me a detailed description; in any case, such a description would be unnecessary and tiresome to those familiar with such things. It would be most desirable if the reader could handle the skulls himself.

Plate II shows the anterior part of the upper jaw of an ox from above, approximately life-size; its flat and broad corpus contains no incisors.

Plate III shows the *os intermaxillare* of a horse; fig. 1 is reduced by a third, and figs. 2 and 3 by half.

Plate IV is the *superficies lateralis interior ossis intermaxillaris* of a horse; the anterior incisor has fallen out and the tooth growing to replace it still lies in the hollow corpus of the *os intermaxillare*.

Plate V is the skull of a fox viewed from three sides. Here the *canales naso-palatini* are oblong and show better closure than in the ox and horse.

Plate VI. The *os intermaxillare* of a lion from above and below. In fig. 1 note especially the suture dividing the *apophysis palatina maxillae superioris* from the *os intermaxillare*.

Plate VII. *Superficies lateralis interior* of the *os intermaxillare* of a young *Trichechus rosmarus* (shown in red for emphasis), together with the greatest portion of the *maxilla superior*.[7]

Plate VIII shows the skull of an ape from the front and from below. In fig. 2 note how the suture emerges from the *canales incisivi*, runs toward the canine tooth, skirts its alveolus, and passes between the next incisor and the canine tooth (quite close to the latter), dividing the two alveoli.

Plates IX (see plates following page 206) and X show these sections in a human skull.

The *os intermaxillare* of man is clearest in fig. 1. We can plainly see the suture separating the *os intermaxillare* from the *apophysis palatina maxillae superioris.* It emerges from the *canales incisivi* (the inferior opening of which merges in a common foramen called the *foramen incisivus,* or *palatinum anterius* or *gustativus*) and disappears between the canine tooth and the second incisor.

In fig. 2 it is more difficult to find evidence of the same suture at the base of the nose. The illustration is not entirely clear, but we can see this suture quite plainly in most skulls, especially younger ones.

The first suture discussed above was noted by Vesalius (Vesalius, *De humani corporis fabrica* (Basel, 1555), bk. I, chapt. 9, fig. II, pp. 48, 52, 53);[8] it is indicated clearly in his illustrations. He says it extends to the anterior side of the canine teeth but never penetrates deeply enough to be thought of as dividing the upper jaw in two. In explaining Galen (whose description is based solely on an animal), Vesalius refers to the first figure on page 46; there he compares the human skull to that of a dog to show the reader the other side of the coin, so to speak, an aspect more clearly delineated in the animal. He does not note the second suture visible at the base of the nose, one emerging from the *canales naso-palatini* and leading to the area of the *concha inferior.* However, both appear in the great osteological work of Albinus, where they are designated with the letter *M* in Plate I.[9] He calls them *suturae maxillae superiori proprias.*

They do not appear in Cheselden's *Osteographia,*[10] nor is there any trace of them in John Hunter's *Natural History of the Human Teeth,*[11] yet they are visible to some degree in every skull, and are impossible to miss if the observer looks carefully.

Plate X shows half an upper jaw from a broken human skull; we see its inner side where the two halves are joined. Two front teeth (the canine tooth and first molar) are missing from the bone which served as a model for the drawing. I did not ask that they be added in the illustration since the missing teeth have no bearing on the present subject, and their absence actually makes it possible to see the *os intermaxillare* without obstruction. In the line drawing I have used red to indicate what is, without doubt, the *os intermaxillare.* The suture can be followed from the alveoli of the incisor and canine tooth through the canals. Beyond the spina or *apophysis palatinae,* which here forms a kind of ridge, it re-emerges and remains visible up to the *eminentia linearis* where the *concha inferior* begins.

I have put a small red star at this point in the line drawing.

If we compare this plate with plate VII we will marvel at how the form of the *os intermaxillare* in a beast like *Trichechus rosmarus* can

teach us to recognize and explain the same bone in man. A comparison of Plate VI, fig. 1, with Plate IX, fig. 1, will clearly show the same suture in both lion and man. Of the ape I will say nothing, for here the correspondence is all too striking.

There can be no doubt, therefore, that this bone is present in man as well as in animal; in our species, however, only some of its edges can be located because the others have grown together and fused with the upper jaw. Thus the outer parts of the facial bones exhibit not the least suture or harmony to hint at the separation of these bones in man.

I believe this is largely a result of the following. This bone, so extraordinarily prominent in animals, is reduced in man to a very small size. If we look at the skull of a child or embryo, we will see how the growing teeth exert such pressure on these parts and so strain the periosteum that the full force of nature is required to weave these bones together. We may compare this to the skull of an animal, where the incisors are shifted quite far forward, thus putting less pressure on each other or on the canine tooth. The same thing happens within the nasal cavity. As noted above, it is possible to trace the suture of the *os intermaxillare* from the *canales incisivi* to the point where the *ossa turbinata* or *conchae inferiores* begin. Here, then, the growth forces of three different bones work upon one another to knit the bones more tightly together.

I am convinced that scientists with deeper insights in this area will be able to enlarge on this point. In addition, I have also found various cases where this bone is partially or completely fused in animals—more could be said about this in the future. There are several other instances of bones which are clearly differentiated in adult animals but no longer distinguishable in human children.

Most of the plates I have included are merely the first efforts of a young artist who improved as he worked; actually, only the third and seventh plates follow Camper's method exactly. I later had the *os intermaxillare* of various animals drawn in full accord with his method; if such a contribution to comparative osteology would be of interest, I would not mind having plates made of this series.[12]

I have found this bone or its traces in cetaceans, amphibians, birds, and fish as well.

The extraordinary variety with which it appears in various creatures really deserves fuller examination; even people with no other interest in this seemingly dry science will find it striking.

It would then be possible to go into more detail and use a precise, step-by-step comparison of many animals to progress from the simplest to the most complex, from the small and limited to the vast and far-reaching.

What a gulf between the *os intermaxillare* of the turtle and the ele-

phant, and yet an intermediate series of forms can be found to connect the two! What none would deny of the entire body could here be shown in a small part of it.

We may survey the living effects of nature as a whole or dissect the remains of its departed spirits; it remains always the same, ever more marvelous.

Here there are also some points of interest to natural history. A major characteristic of our bone is that it contains the incisors, and thus it follows that the teeth inserted in the bone must be considered incisors. Until now the existence of incisors has been denied in *Trichechus rosmarus* and the camel, but unless I am greatly mistaken we can ascribe four incisors to the former and two to the latter.

And so I will close this short essay with the wish that it find no disfavor among students and friends of natural philosophy;[13] indeed, I hope it will give me the opportunity to work more closely with them and, where possible, to make further progress in this captivating science.

Excerpt from "Outline for a General Introduction to Comparative Anatomy, Commencing with Osteology"[1]

I. Of the Advantages of Comparative Anatomy, and the Obstacles It Faces

Natural history is largely based on comparison.

External characteristics are important, but are neither sufficient for separating organisms properly nor for recombining them.

Anatomy does for organized beings what chemistry does for unorganized matter.

Comparative anatomy approaches the mind from many directions, and gives us a chance to see organisms from several points of view.

Animal dissection has quietly kept pace with human dissection.[2]

Discoveries made in animals have greatly expanded our insight into the structure and physiology of the human body.

Nature has distributed various traits and peculiarities among the animals; each finds expression in a characteristic way. The structure of animals is simple, scant, often expanded into a large, broadly layered bulk.

The structure of the human being is diversified into more delicate ramifications, richly and fully equipped, condensed at significant points, with its separate parts joined by anastomosis.

In the animal we can clearly see the animal nature with all its direct demands and needs.

In man the animal nature is transmuted for higher purposes, and it remains hidden in the shadows for the eye as well as the mind.

Many are the obstacles which have impeded comparative anatomy. The field has no boundaries, and any purely empirical investigation exhausts itself in a vast extent.

Observations have remained as disparate as the circumstances under which they were made. It was impossible to reach agreement on terminology. Scholars, horsemen, hunters, butchers, etc., traditionally used different sets of names.

No one was willing to believe in a common reference point for things, nor in a common point of view on them.

As in other sciences, a more refined kind of thinking was too seldom applied. Researchers either treated the matter too superficially and failed to get beyond the phenomenon, or resorted to ultimate causes which only led further and further from the idea of a living being. A pious approach was equally a hindrance, and for the same reasons; it strove to apply every detail directly to the glorification of God. It lost itself in empty speculation, e.g., on the souls of animals, etc.

To pursue human anatomy in detail called for an immense amount of work. Even though a part of medicine, it was a specialty practiced by only a few. Even fewer had the inclination, time, ability, and opportunity to accomplish something important and consistent in comparative anatomy.

II. On an Archetype to Be Established As an Aid to Comparative Anatomy

The similarity of animals to one another and to man is obvious and widely known, but more difficult to see in practice, not always directly apparent in detail, frequently misunderstood, and sometimes even denied. Differing views are therefore difficult to reconcile, for there is no norm to which the different parts may be compared, no set of principles to profess.

All the work of comparing animals to man and to one another was directed to some particular end; the accumulation of detail made it increasingly difficult to attain some sort of overview. Many would find examples of this in Buffon. Josephi's work, and that of others, should be equally considered.[3] Thus it was found necessary to compare all animals with every animal and every animal with all animals—and we can see the impossibility of reconciling things in this manner.

Hence, an anatomical archetype will be suggested here, a general picture containing the forms of all animals as potential, one which will guide us to an orderly description of each animal. As much as possible, this archetype must be established physiologically. The mere idea of an archetype in general implies that no particular animal can be used as our point of comparison; the particular can never serve as a measure for the whole.

With all his exalted perfection as an organism—in fact, just because of this perfection—the human being cannot serve as a gauge for the imperfect animals. Instead, let us proceed as follows.

Empirical observation must first teach us what parts are common to all animals, and how these parts differ. The idea must govern the whole, it must abstract the general picture in a genetic way.[4] Once such an archetype is established, even if only provisionally, we may test it quite adequately by applying the customary methods of comparison.

Animals have been compared to one another, as have animals to man, the races of man to one another, the two genders to each other, the principal parts of the body (e.g., upper and lower extremities), and the subordinate parts (e.g., one vertebra to another).

We may still make any of these comparisons after we have established the archetype, but then more consistently and with more meaning for the whole of science. They can even serve to test earlier results and organize observations found to be true.

Comparison to the established archetype may be undertaken in two ways. First, by describing individual species in terms of the archetype. Once this is done there is no need to compare animal with animal, for when the descriptions are placed side by side the comparison will be made. Second, a particular part of the archetype may be traced descriptively through all the major genera, thus giving us a thorough and instructive comparison. But if studies of either sort are to bear fruit, they must be as complete as possible. The latter sort, especially, might call for collaboration between several observers, although first they would have to agree on a common approach. It would help with the mechanics of their work if each collaborator had the approach in schematic form as the basis for his own contribution;[5] then the researcher in even in the most minute and specialized area could be certain that he was working for all, for science. The sad thing about the present state of affairs is that everyone must start again at the beginning.

III. Very General Description of the Archetype

The above really refers only to the comparative anatomy of mammals, and ways of making this study easier. But in establishing the archetype, we must look further afield in nature; we will be unable to form a general picture of mammals without such an overview, and by calling on all of nature when we construct this picture we will be able to modify it by regression to produce pictures of less perfect creatures.

Even in their outer structure, all relatively developed creatures exhibit three main sections. Just observe the fully developed insects! Their bodies consist of three parts which perform different vital functions; the interconnection and mutual effect of these parts represents organic existence on a higher level. These three parts are the head, the midsection, and the rear section. Auxiliary organs are affixed to these in a variety of ways.

The head is always the forward part; there the individual senses meet, and there the governing organs of sense are bound together in one or more ganglia, which we usually call the brain. The midsection contains the organs for inward maintenance of life and constant movement outwards; the organs of the inner life impulse are less important in the

insect, since each part of this creature seems to be endowed with its own life. The rear section contains the organs of nourishment and reproduction, as well as those of grosser elimination.

The separation of these three parts, often joined only by threadlike tubes, shows a state of perfection. Thus the main element in the repeated metamorphoses of an insect is the successive separation of systems hidden beneath the sheath of the larva, and partially present in a latent, undeveloped state. But when the development is complete—when every faculty performs its task—free movement and activity is found in the creature, and reproduction becomes possible through various processes of definition and separation in its organic systems.

In the fully developed animals, the head is separated rather decisively from the second section. But the third section is joined to the second by a lengthened backbone and a common covering, although dissection will show a diaphragm between the third section and the middle system in the breast.

Auxiliary organs are present in the head insofar as they are needed to ingest food; sometimes they appear as pincers, and sometimes as mandibles which may be connected to some degree.

In the less developed animals the midsection has a large variety of auxiliary organs: feet, wings, and wing covers. In the more developed animals the midsection is where the middle auxiliary organs are found: arms or forefeet. In developed insects the rear section is without auxiliary organs, but in developed animals (where the two systems lie compressed together) the final auxiliary organs (called feet) are at the end of the third system. Thus we find the structure of mammals to be consistent. Their last or hindmost part may have a further extension (the tail), but this can be considered simply an indication of the infinite variety of organic life forms.

IV. Application of the General Description of the Archetype to the Particular

The parts of the animal, their respective forms, their relationship, and their individual qualities, determine the creature's needs in life. Thus the definite but limited habits of animal genera and species.

If we compare our general archetype to the different parts of the most developed animals (which we call mammals), we will find that a limit is set to nature's structural range, but the number of parts and their modifications allow for the form to be changed ad infinitum.

After recognizing these parts and examining them well, we will find that the many varieties of form arise because one part or the other outweighs the rest in importance.

Thus, for example, the neck and extremities are favored in the giraffe at the expense of the body, but the reverse is the case in the mole.

In the above observation we encounter this law: nothing can be added to one part without subtracting from another, and vice versa.

These are the bounds of animal nature; within these bounds the formative force seems to act in the most wonderful, almost capricious way, but is never able to break out of the circle or leap over it. The formative impulse is given hegemony over a limited but well-supplied kingdom. Governing principles have been laid down for the realm where this impulse will distribute its riches, but to a certain extent it is free to give to each what it will. If it wants to let one have more, it may do so, but not without taking from another. Thus nature can never fall into debt, much less go bankrupt.

With this thread we will seek to find our way through the labyrinth of animal structure; later we will discover that the thread also reaches down to the most formless organisms. We will test it against the forms, so that later we can apply it to the underlying forces.

Hence we conceive of the individual animal as a small world, existing for its own sake, by its own means. Every creature is its own reason to be. All its parts have a direct effect on one another, a relationship to one another, thereby constantly renewing the circle of life; thus we are justified in considering every animal physiologically perfect. Viewed from within, no part of the animal is a useless or arbitrary product of the formative impulse (as so often thought). Externally, some parts may seem useless because the inner coherence of animal nature has given them this form without regard to outer circumstance. Thus, in the future, members such as the canine teeth of the *Sus babirussa*[6] will not elicit the question, What are they for? but rather, Where do they come from? We will not claim that a bull has been given horns so that he can butt; instead, we will try to discover how he might have developed the horns he uses for butting. On the whole we will find our general archetype to be unchanging, although we have first to construct it and examine it in detail. Even the highest class of animal, the mammal in all its various forms, we will find to be quite consistent in its parts.

But now that we have endured in the realm of what is enduring, we must also learn to change our views along with ever-changing nature. We must learn many different movements so that we grow deft enough to follow the archetype in all its versatility, and so that this Proteus never slips from our grasp.[7]

If we ask what causes the appearance of this ability to assume manifold shapes, we will at first answer that the animal is formed by circumstances for circumstances; hence its inner perfection and its outer practicality.

To make our idea of an economic give and take concrete, we will

cite some examples. In its organization, the snake emphasizes the forward part. It has a well-defined head equipped with a perfect auxiliary organ, a lower jaw which is extensible. But its body is practically endless, and this is possible because neither material nor energy are required for auxiliary organs. When these organs appear in another form (as, for instance, in the lizard with its short arms and feet), the undefined length must contract and a shorter body will be created. The long legs of the frog force its body into a very short form, and the misshapen toad is broadened by the same law.

It is up to us to decide how far we want to go in tracing the continuity of this principle through the various classes, genera, and species of natural history—how concrete and approachable we want to make the general idea by examining behavior and external characteristics. We will then feel the desire and courage to sift through the details carefully and attentively.

But first the archetype would have to be considered from the standpoint of how the various elemental forces of nature affect it, and how it is also somewhat subject to the general laws of the external world.

Water has a marked bloating effect on bodies it surrounds, touches, or penetrates to some degree. Thus the body of the fish, and especially its flesh, is swollen in conformity with the laws of the element. According to the laws of the archetype, this swelling of the body must be followed by a contraction of the extremities or auxiliary organs, not to mention further limitations of other organs as will be shown later.

The air, by absorbing water, has a drying effect. Hence the archetype developed in the air will be as inwardly dry as the air is pure and lacking in moisture, giving rise to a more or less lean bird. Enough material will be left over for the formative force to clothe flesh and bone in rich array, and outfit the auxiliary organs fully. What in the fish was used for flesh is here left over for the feathers. Thus the eagle is formed by the air for the air, by the mountain peak for the mountain peak.[8] The swan and the duck, amphibians of a kind, betray their liking for the water through their very shape. It is worthwhile to consider how marvelously the stork and the sandpiper show both an association with water and an inclination to air.

We will find the effect of climate, altitude, heat and cold, together with that of water and common air, to be quite powerful in the formation of the mammal as well. Heat and moisture have a bloating effect and produce apparently inexplicable monsters, even within the limits of the archetype; heat and dryness produce the most perfect and fully formed creatures, no matter how they may differ from man in nature and form—the lion and tiger, for example. Thus only a hot climate is able to impart a semblance of man to imperfect organisms, as happens in the ape and parrot.

It is also possible to observe relationships within the archetype, make comparisons within the archetype itself. We may, for example, compare the hard parts to the soft parts. The organs of nourishment and reproduction seem to consume far more energy than the organs of movement and circulation. The heart and lungs are firmly seated in a bony housing, while the stomach, intestines, and uterus float in a soft enclosure. We can see that the formative plan calls for a breastbone as well as a backbone. But the breastbone (on the underside in animals) is short and weak in comparison to the backbone. The vertebrae of the breastbone are longish and narrow or broad in shape; where the backbone adjoins full or partial ribs, the breastbone has only cartilage. Thus the breastbone appears to sacrifice part of its potential for the upper organs, and the whole of its existence for the lower ones. The backbone itself likewise sacrifices the potential rib structure at the lumbar vertebrae to a complete development of the important adjoining soft parts.

If we now apply this law to related natural phenomena, it will help explain many an interesting fact. The distinctive feature of all female animals is the uterus. It occupies an important position among the intestines, and exerts the greatest actual or potential force of attraction, expansion, contraction, etc. In the more perfect animals, the formative force seems to need so much for this part that it must deal more sparingly with the others. This might explain the drab appearance of the hen: so much was needed for the ovaries that an outer brilliance was rendered impossible. Many such instances will be found in our work, but we will not anticipate them here.

Through all these observations we will finally ascend to the human being; we will ask when (and if) we can find man on the highest level of organization. We hope that our thread will lead us through this labyrinth, clarifying various anomalies in the human form and at last offering an explanation for this most beautiful of structures.

V. On the Osteological Archetype in Particular

Whether this conceptual approach is truly appropriate for the subject under consideration is a question only a thorough anatomical dissection and comparison of parts can answer. Our method of organizing the parts will also find its justification only through trial and error.

The skeletal structure is the clear framework for all forms. Once understood, it will make recognition of the other parts easier. Here, of course, it is necessary to discuss several points before proceeding. What, for example, is the background of human osteology? We should also say something about the *partes proprias et improprias*.[9] But at the moment we can do so only briefly, aphoristically.

First, we may state without fear of contradiction that the classification of the human skeleton has been done by mere accident. This is why some descriptions indicate more bones than others, and why each researcher has his own way of describing and arranging these bones.

It would also be important to explore the contributions of so many different researchers to the osteology of mammals; here Camper's[10] review of the most important works on comparative osteology would be of help.

On the whole, we are convinced that even general comparative osteology has been thrown into great confusion by the lack of a prototype divided into well-defined parts. Volcher-Coiter, Duvernay, Daubenton,[11] and others were unable to avoid confusing parts—an inevitable error in the first stage of any science, but especially understandable in this one.

Certain rigid opinions became established. It was denied, for instance, that the human being has an intermaxillary bone. The reason for this was strange enough—this trait was to distinguish us from the apes. No one realized that the indirect denial of the archetype deprived osteology of a promising approach.

Moreover, for a time the claim was made that the canine tooth of the elephant is seated in the intermaxillary bone. This tooth, however, is irrevocably a part of the upper jawbone; a careful observer can see that a lamella runs from the upper jawbone and around the enormous tusk.[12] Here nature permits nothing to contradict its law and order.

We have said that the human being cannot serve as the archetype for the animal, nor the animal for the human being. Thus we will not hesitate to suggest a third thing, intermediate between the two; the reason for our approach will gradually become clear.

We must search out and note every bone segment we can find; we will do so by examining a variety of animal species, and even the fetus.

The four-footed animal stands before us with its head extended to the front, and so we shall consider it front to back by first building up the skull, then the rest. We will express some of our guiding concepts, thoughts, and observations; others will be implied, and explained later. Let us then proceed to present our first scheme.

VI. The Osteological Archetype Organized in Its Parts

A. The head.

a. *Ossa intermaxillaria*
b. *Ossa maxillae superioris*
c. *Ossa palatina*.

These bones are comparable in more than one sense: they form the foundation of the face and front part of the head; taken together they make up the palate; in form they have much in common. They come first because we are describing the animal front to back. The first two obviously form the foremost part of the animal's body, and also give full expression to the character of the creature, since their form determines how the animal nourishes itself.

d. *Ossa zygomatica*
e. *Ossa lacrymalia*

We will place these on the previous bones to form the face more perfectly; this also completes the lower edge of the eye sockets.

f. *Ossa nasi*
g. *Ossa frontis*

We will set these on top, thus creating the upper edge of the eye sockets, space for the organs of smell, and the vault for the forebrain.

h. *Os sphenoideum anterius*

We will add this as a foundation from below and behind, thus preparing a bed for the forebrain and exits for several nerves. In man, the corpus of this bone is always fused with the corpus of the *Os posterius*.

i. *Os ethmoideum*
k. *Conchae*
l. *Vomer*

Thus the instruments of smell find their place.

m. *Os sphenoideum posterius*

This follows the above bones. The foundation of an enclosure for the brain is now nearing completion.

n. *Ossa temporum*

These form the partitions above the enclosure; they are joined in front.

o. *Ossa bregmatis*

These cover this section of the vault.

p. *Basis ossis occipitis*

This is similar to the two sphenoid bones.

q. *Ossa lateralia*

These form the partitions, and are similar to the *Ossa temporum*.

r. *Os lambdoideum*

This finishes the structure, and is similar to the *Ossa bregmatis*.

s. *Ossa petrosa*

These contain the instruments of hearing, and are inserted at the empty spot.

These are the last of the bones forming the structure of the head and fitted immovably together.

Excerpt from "Tibia and Fibula"[1]

After completing work on my own concept of the general osteological archetype in 1795,[2] I felt a desire to use this approach in describing the bones of mammals individually. I was assisted by the fact that I had previously distinguished the intermaxillary bone from the upper jawbone; I was equally helped by my recognition that the inextricable sphenoid bone consisted of two parts, an anterior and an exterior part. In this way I set about dividing the temporal bone into its various natural parts, a division not made in earlier diagrams and concepts.

For years already I had labored in vain along the traditional path, and had wondered if another path—a better one—might not open up for me. I readily admitted that human anatomy required infinite precision in describing each part of the individual bone and grasping the manifold variations in every aspect of the bone. The surgeon must know how to find the inner wound with eyes of the mind, sometimes without the help of his sense of touch; thus he finds it necessary to apply the most exacting knowledge of detail to gain a kind of penetrating omniscience.

After long and fruitless labor, however, I realized that this approach is ill-suited to comparative anatomy. If we try to use it, we will see immediately that it is impossible to apply across the whole of the animal kingdom. Obviously, neither memory nor books could incorporate such learning, and no power of imagination would be able to recreate it in a formed way.

Another proposed method of differentiation and description based on number and quantity proved equally useless for a presentation which had life. In their sterility, number and quantity dissolve form and banish the spirit of a living perception.[3] I therefore sought another way of describing individual bones, but through a constructive interrelationship; thus my first effort to differentiate the petrosa and bulla from one another, and also from the temporal bone.

A second short essay describing the ulna/radius and tibia/fibula will show how I went about the comparison; i.e., serially. Here the skeleton

was considered as a living entity, as a basic precondition for all organic formations on a higher level; thus the relationship and task of the individual parts was kept firmly in view. I proceeded serially in order to orient myself somewhat; this work was only meant as a kind of preliminary catalog. The underlying intention—when the opportunity presented itself—was actually to collect the limbs for comparison in a museum; it would then become self-evident that each series of limbs requires a different comparative thrust.[4]

On Granite[1]

Even in antiquity granite was recognized as a mineral worthy of note and it has drawn increased attention in modern times. The ancients knew it under another name; they called it *syenite* after Syene, a town located on the border of Ethiopia. The colossal masses of this stone served to inspire the Egyptians with the idea of creating monumental works. Their kings erected obelisks of it to honor the Sun, and because of its variegated red color it was soon named "the stone with flecks of fire." Today the sphinxes, the statues of Memnon, the enormous columns still strike travelers with awe, and in our own time the powerless lord of Rome is even setting up the relics of an ancient obelisk which his omnipotent predecessors brought intact from foreign soil.[2]

Modern observers have given this mineral its present name because of its granular appearance. In the recent past it was subjected to a moment of degradation before attaining the esteem in which informed scientists now hold it: the tremendous masses of those obelisks and the extraordinary variations in their granularity misled an Italian scientist into believing that the Egyptians had molded them artificially from a fluid mass.

But that view was soon abandoned, and the honor of this mineral was finally restored by a number of observant travelers. Every journey into uncharted mountains reaffirmed the long-standing observation that granite is the loftiest and deepest-lying substance, that this mineral, which modern research has made easier to identify, forms the fundament of our earth, a fundament upon which all other mountains rest. It lies unshakably in the deepest bowels of the earth; its high ridges soar in peaks which the all-surrounding waters have never risen to touch. This much we know of granite, and little else. Composed of familiar materials, formed in mysterious ways, its origins are as little to be found in fire as they are in water.[3] Extremely diverse in the greatest simplicity, its mixtures are compounded in numberless variety. The position and relationship of its elements, its durability and its color vary from peak to peak, and the rock masses of each peak often exhibit variations every

few feet although the whole remains homogeneous. And thus anyone who knows the fascination natural mysteries hold for man will understand why I have departed from my usual realm of observation and turned with passionate fervor to this one. I do not fear the accusation that a contrary spirit has led me away from my consideration and depiction of the human heart, the youngest, most diverse, most fluid, most changeable, most vulnerable part of creation, and has brought me to the observation of the oldest, firmest, deepest, most unshakable son of nature. It is evident that all things in nature have a clear relationship to one another, and that the questing spirit resists being denied what it can attain. I have suffered and continue to suffer much through the inconstancy of human opinion, through its sudden changes in me and in others, and I may be forgiven my desire for that sublime tranquillity which surrounds us when we stand in the solitude and silence of nature, vast and eloquent with its still voice. Let those who are aware of this feeling follow me on my journey.

Filled with these thoughts I approach you, the most ancient and worthiest monuments of time. As I stand high atop a barren peak and survey the wide expanse below, I can say to myself: "Here you stand upon ground which reaches right down into the deepest recesses of the Earth; no younger strata, no pile of alluvial debris comes between you and the firm foundation of the primal world. What you tread here is not the perpetual grave of those beautiful, fruitful valleys; these peaks have never given birth to a living being and have never devoured a living being, for they are before all life and above all life."

In this moment, when the inner powers of the Earth seem to affect me directly with all their forces of attraction and movement, and the influences of heaven hover closer about me, I am uplifted in spirit to a more exalted view of nature. The human spirit brings life to everything, and here, too, there springs to life within me an image irresistible in its sublimity.

"This mood of solitude," I say to myself as I gaze down from the barren peak and glimpse a faint patch of low-growing moss far below, "this mood of solitude will overcome all who desire to bring before their souls only the deepest, oldest, most elemental feeling for the truth. Such a one may truly say to himself: 'Here, on this primal and everlasting altar raised directly on the ground of creation, I bring the being of all beings a sacrifice. I feel the first and most abiding origin of our existence; I survey the world with its undulating valleys and its distant fruitful meadows, my soul is exalted beyond itself and above all the world, and it yearns for the heavens which are so near.' "

But soon the burning sun will bring back thirst and hunger, the human necessities. Our observer's gaze will seek out the very valleys over which his spirit had soared. He will envy the dwellers in those more abundant and plentifully watered plains, the inhabitants who have built

their happy homes on the debris and ruin of error and opinion, who scratch in the dust of their ancestors and quietly meet the modest needs of their daily existence within those narrow confines. With these thoughts as an overture his soul will make its way into centuries past and recall all that was noted by careful observers, all that was imagined by fiery spirits.

"This crag," I tell myself, "rose more steeply, more sharply, higher into the clouds when its summit still stood as a sea-girt isle in the ancient waters. Round about it streamed the spirit which moved on the face of the waters; in the vast depths the taller peaks were shaped from the debris of primeval mountains, while newer and more distant mountains were formed from the ruins of those peaks and the remains of what lived in the depths. Now the moss has started to spread, the shell-covered creatures of the sea become fewer, the water recedes, the taller peaks grow green, everywhere life begins to burgeon.

"But soon new scenes of devastation clash with this life. Raging volcanoes rise up in the distance, seeming to threaten the world with destruction. Yet the bedrock of my refuge remains unshaken, while those who live on distant shores and islands are buried beneath the faithless land."

I return from these far-ranging thoughts and view the very rocks which have brought exaltation and assurance to my soul by their presence. I see their bulk shot through with cracks, here rising straight up, there askew, sometimes sharply layered, sometimes in formless heaps as though thrown together. At first glance I am tempted to exclaim: "Nothing here is in its primal, ancient state; everything is ruin, chaos, and destruction!" This is exactly the opinion we will meet when we turn from direct observation of these mountains and retreat to the library to delve into the books of our predecessors. Here we will find it asserted that the primeval mountains are an indivisible whole, seemingly cast in a single piece, or that they are divided by fissures into layers and strata which are crisscrossed by innumerable veins of rock; sometimes it is said that this mineral is not stratified, but occurs in individual masses which are intermixed in a completely irregular fashion, while another observer claims to have found strong stratification alternating with muddled confusion. How can we harmonize all these contradictions and find a guidepost for our further investigations?

This is a task which I presently intend to undertake. Though I may not be as fortunate in this as I would hope, my efforts will afford others the opportunity to go further—even errors in observation can serve to cultivate the quality of alertness and give those with sharp eyes reason to use them. Here, however, an admonition may be warranted, less for Germans than for those in other lands to whom this treatise might find its way. Learn how to distinguish this mineral clearly from other varieties. To this day the Italians confuse fine-grained granite with a

type of lava, and the French confuse it with gneiss, which they call foliated granite or second-order granite. In fact even we Germans, as conscientious as we usually are in such things, have until recently confused granite with a useless rock chiefly found among layers of schist, a conglomerate of quartz and varieties of hornstone, as well as with the graywacke of the Harz mountains, a younger mixture of quartz and schist particles.

Suggestions for a Comparative Approach Reconciling the Plutonists and Neptunists on the Question of the Origin of Basalt[1]

Several factors have served to inspire and support the notion that basalts are volcanic: the similarity of basalts and lavas in composition and external appearance, the proximity of the two minerals in mountainous areas, the way they merge into one another. Further research has brought several problems to light: no craters could be discovered from which scattered outcroppings or extended flows of basalt might have come in liquid form, a close relationship was established between basalt and several other minerals clearly formed in water, and these minerals were found to fluctuate in character between the type associated with primal rock masses and the type associated with stratified rock masses. Too much had been ascribed to the action of fire; now there was a similar tendency to claim that everything was traceable to the action of water. The close relationship between basalts and volcanoes is undeniable, and even the neptunists now recognize this when they assert that lavas are molten basalts. Thus even if the basalts are not volcanic in origin, the lavas are basaltic; this suggests a point of reconciliation for both sides.

This is our hypothesis. The so-called primal rock masses had already been deposited out of the substance of the vast sea covering the earth. This sea then became seething hot as certain elements contained in it began to affect one another more strongly and directly. During this hot period the basalts were deposited; by the end of this period so much combustible material had settled with the basalt that even today volcanoes continue to burn near the sea.

Thus basalts were the products of a universal volcanic sea. Here no craters were necessary, nor any effluvium—only a vast, hot, burnt-out deposit. The basaltic material not yet neutralized continued its ceaseless activity beneath the water: it produced incrustations, its forces worked in caverns below the surface, it heaped up layer upon layer of crust, and tore them apart again. Parts of the interior became molten and expanded; thus the volcanic islands and oceanic mountains rose, enormous ocean gulfs were filled, and entire ranges of volcanoes appeared along the coasts.

It is here that the relationship is to be found between basalts and volcanoes.

This explains how:

1) Basalts could exist where there was no later volcanic activity in the depths of the ancient sea, and none in the epoch that followed.

2) Volcanic effects could have occurred in the original basalts, and then caused them to remelt.

3) Volcanoes could have arisen where basalts were never formed, but where combustible material had simply been deposited in the sea.

4) In the second and third instances basalt-like lavas could have been formed.

It is easy to see that our hypothesis fits both views on this subject. We pass along these thoughts not as a final solution, but as a suggested comparative approach for consideration by the two parties. It is our hope that we will not meet the usual fate of peacemakers and become the object of disdain on both sides.

Note: It is unnecessary to assume tremendous revolutionary changes which eliminated the craters leaving only their basaltic cores. Instead, the above hypothesis meets the demands of the neptunists by making the basalts a major type of rock mass, more closely related to the primal rock masses in some cases and to the stratified rock masses in others.

In this way we will not have to resort to iron pyrites to explain the heating effect.

A More Intense Chemical Activity in Primordial Matter

In speaking of primal beginnings we should speak primally, i.e., poetically. Of those things to which our everyday language pertains—experience, understanding, judgment—none is adequate to the task. Upon entering deep into these barren, rocky chasms I felt for the first time that I envied the poets.[1]

We must suppose that all primordial matter had greater energy, more intense chemical activity, and a stronger gravitational pull. Projecting rocks attracted the heavy particles suspended in the water to form a deposit, not below, but on their flanks. Parts of this solution may also have sunk to the bottom, thus producing the ambiguous quality of many formations. It is important to note that the solidification was always accompanied by seismic shocks.

The oldest epochs were altogether more uniform and homogeneous in nature, the newer ones more diverse, more or less dissimilar.

My Relationship to Science, and to Geology in Particular [Outline for an Autobiographical Sketch]

From youth on we are taught to view the sciences as subjects we can lay hold of, use, command.

Without this belief there would be no desire to learn anything.

And yet every person deals with the sciences as his character dictates.

The young man demands certainty, demands a didactic, dogmatic style of presentation.

With deeper study we also see how the subjective element plays a true role in the sciences. Our efforts will not prosper until we come to know ourselves and our own character.

But our individuality, no matter how clear-cut, depends on the time and place in which it is set. Thus these accidental factors will affect our inherent nature.

This was made especially clear to me when inclination and practical necessity led me to enter science, reach certain conclusions, and pursue their implications. The time came when a particular approach formed and established itself in me; I weighed and judged objects in accord with this approach.

Thus I absorbed what suited me, rejected what nettled me, and since I had no need to give public instruction, I educated myself in my own way without adopting any given or traditional approach.

This allowed me to take up every new discovery with enthusiasm and pursue the investigation of things I myself had come upon.

I profited from the useful without having to bother with the odious.

In the sciences, however, a continual circulation takes place—not because the objects themselves change, but because new observations produce a need in each scientist to assert himself, to handle knowledge and the sciences in his own way.

But since human thought also follows a certain circular pattern, a reversal of method will always bring us back to the same point. Thus atomistic and dynamic concepts[1] will forever alternate, but only in emphasis, for neither will wholly replace the other. This holds true even for the individual scientist. Before he realizes it the most determined

dynamist will fall into atomistic terminology, while the atomist will be unable to avoid becoming dynamistic at times.

We find a parallel in the . . . [omission by Goethe][2] and esthetic methods, where one is merely the opposite of the other: when working with subjects in a living way sometimes one will be of use, and sometimes the other.

I have been led to describe the course of my geological studies by the emergence of an approach completely counter to my own, one I cannot accept although I have no intention whatever of entering into a dispute with it.[3]

Every statement we make is a confession of faith, and thus I will begin my own in this area.

Geology

Interest in natural objects and other things of the visible world.

Need to share my views with others.

Depiction through imagery.

Awareness of this approach also when I began to deal with natural history and natural philosophy.

After mentioning my osteological illustrations, I should speak here of a similar project applied to the skeletal structure of the earth, geology.

Mines at Ilmenau.[4]

Application to the study of the earth's interior; how it reveals itself outwardly or has been explored within.

First journey in the Harz mountains during winter; a dithyrambic poem about this journey still exists.[5]

Ongoing observation of rock forms.

Masses which split apart.

Conviction that this splitting follows certain laws.

Difficulty in expressing this.

Attempt to do so.

Rock fissures which run vertically or nearly so.

Oriented more or less clearly toward the cardinal points of the compass and traversed by other fissures (seldom at right angles, most frequently at an acute angle, thereby creating rhomboidal fragments).

Many observations made to provide more positive information on the orientation of the above shapes toward the cardinal points of the compass.

It seemed apparent that the alignment of the fissures toward the north occurred during the solidification of the rock (with the oblique east-west clefts not crossing at right angles however, thus creating the rhomboidal splintering).

Proposal to create a model.
Preliminary studies for this to be made from nature.
We therefore needed to assemble accurate drawings.
Trip to the Harz mountains in August, 1784, with Councillor Kraus.[6]
Short biographical sketch.
Artistic, social qualities of this man.
All these drawings intended to show the details of fracturing, division, and form in groups of mountains and rocks. This was also the subject of diary notations (unfortunately all too brief).

The diary to be published with notes clarifying the intention, and at the same time the drawings to be shown in a clear and useful way for future reference.

Jena
October 7, 1820

Luke Howard to Goethe: a Biographical Sketch[1]

The next issue of *On Natural Science* will feature a translation of this important manuscript, which I have just received. I am sure it will please all who seek such knowledge, but now I will say only the following about it.

My affinity for Howard's method of cloud classification is evidenced throughout the pages of *On Natural Science,* which is really where this report belongs.[2] My desire to see the formless formed, the infinite arrayed in regular sequence of form, follows from all my work in science and art. I sought to immerse myself in this set of principles, applying them as well as I could at home and away, in every season and under different barometric conditions. I always found this descriptive terminology useful, although I conducted my studies under widely different states of transition and combination. Nature served as the model for many sketches, and I tried to fix my ever-mobile subject on paper in accord with the concept. I have turned to artists for help, and may soon be able to publish a satisfactory series of illustrations showing characteristic forms; until now there has been a regrettable, universal lack of such illustrations.

I have become increasingly convinced that everything done by the hand of man ought to be looked at in an ethical sense. But moral value can be judged only through biography, so I asked Mr. Hüttner,[3] my able correspondent in London, to see if he could obtain even the barest outline of Howard's life for me. Thus I could see how such a mind took form, and how it was led to view nature in a natural way, give itself over to her, recognize her laws, and then act in a way both natural and human as it prescribed such laws for her.

My verses in honor of Howard[4] had been translated in England, and commended themselves especially by the addition of an explanatory introduction in verse. They were published and known, and thus I had reason to hope that some well-wisher might respond to my request.

But the results surpassed even my expectations when I received a letter from Luke Howard himself, and with it a complete history of his

family, life, education, and opinions, all written with the greatest clarity, precision, and frankness. He was also kind enough to give me permission to publish this. There is probably no finer example of a spirit to whom nature shows herself without reserve, a soul with which she is inclined to hold the most intimate communion.

I found this charming document irresistible the minute I received it, and I had the greatest pleasure in translating it. It will adorn the pages of the next issue of *On Natural Science*.[5]

Excerpt from "Toward a Theory of Weather"[1] 1825

General Introduction

We can never directly see what is true, i.e., identical with what is divine; we look at it only in reflection, in example, in the symbol, in individual and related phenomena. We perceive it as a life beyond our grasp, yet we cannot deny our need to grasp it.

This applies primarily to phenomena of the tangible world, but here we will speak only of the less tangible principles of weather.

Weather manifests itself to the active human being mainly through heat and cold, through humidity and dryness, and through moderate and immoderate degrees of these conditions. We experience all this in a direct way, without further thought and research.

Many instruments have been invented to measure in degrees these phenomena that affect us daily. The thermometer engages everyone's attention: whether we are sweating or freezing, we seem somewhat more content when able to express our suffering in degrees Reaumur[2] or Fahrenheit.

Less attention is paid the hygrometer. Daily and monthly, we simply accept humidity and dry air as they come. But the wind is everyone's concern: the ubiquitous wind vane lets everyone know whence it blows and whither it goes, although what this means in a larger sense remains as much a mystery as the other phenomena.

It is remarkable, however, that the most important effect on atmospheric conditions is the least noted by the common man: a sickly constitution is needed to feel those atmospheric changes shown by the barometer, and a more advanced education to observe them.

These were long hidden from us because they manifested themselves as various degrees of pressure—in succession at one place, or simultaneously at several places, and at different altitudes. In our time, this aspect of the atmosphere plays a leading role in weather observations; we will also give it special importance.

Above all we must remember that nothing that exists or comes into being, lasts or passes, can be thought of as entirely isolated, entirely

unadulterated. One thing is always permeated, accompanied, covered, or enveloped by another; it produces effects and endures them. And when so many things work through one another, where are we to find the insight to discover what governs and what serves, what leads the way and what follows? This creates great difficulty in any theoretical statement; here lies the danger of confusion between cause and effect, illness and symptom, deed and character.

The serious observer has no choice but to chose some midpoint and then see how he can deal with what is left on the periphery. This is what we have attempted to do, as the following will show.

Thus it is actually the atmosphere in which and with which we will now be occupied. We dwell in it as inhabitants of the seashore. We gradually ascend to the highest peak where it is difficult to live, but in thought we climb further. We have ventured to think of the moon, the other planets and their moons, and finally the fixed stars, as collaborating in the whole; and the human being, who necessarily refers everything to himself, goes on to flatter himself with the notion that the universe, of which he is but a part, really exerts a special and noticeable effect on him.

In the face of reason he may have given up his astrological whimsey; i.e., that the starry heavens rule the fate of man. Nonetheless, he could not drop the conviction that the planets (if not the fixed stars), or the moon (if not the planets), determine and define the weather in a regular way.

But we will reject any such effect and consider weather phenomena on the earth to be neither cosmic nor planetary; it is our premise that they may be explained in purely tellurian terms.

Resumption

Accordingly, we will assume two basic movements of the earth's living body, and will consider all barometric effects as symbolic expressions of these.

First, the so-called oscillation of the earth[3] directs us to a regular movement around the axis which produces the rotation of the earth, and thus day and night. This moving element falls twice in twenty-four hours, and rises twice; this has been shown by a variety of earlier observations. We can imagine it as a living spiral, a living helix without end. Its effect of attraction and release appears in the daily rise and fall of the barometer in relation to its normal level. This must be most pronounced where the greatest mass revolves, and must diminish toward the pole, finally disappearing altogether; observers have already shown this to be true. The rotation has a decided effect on the atmosphere, for clear skies and rain appear in daily succession. . . .

The second generally recognized movement is one which causes an increase and decrease in gravity; we can compare it to an inhaling and exhaling from the center toward the periphery. We have considered the rise and fall of the barometer as a symptom of this.

Control and Release of the Elements[4]

In continuing to consider, apply, and test the above, we will be led further by events around us; let us therefore add the following about what was discussed earlier.

It is obvious that what we call the elements have a constant urge to go their own wild and brutal way. Where man has taken possession of the earth and is obliged to keep it, he must be forever vigilant and ready to resist. But these individual defenses are not nearly so effective as the use of a law to counter the unruly. Here nature has prepared the way for us in a most wonderful fashion by setting an alive, formed existence against the formless.

Thus the elements are to be viewed as colossal opponents with whom we must forever do battle; in each case we can overcome them only through the highest powers of the mind, by courage and cunning.

We may say that the elements are willfulness itself; the earth continually strives to seize the water and force it to solidify, annex it as earth, rock, or ice.

With equal turbulence the water would hurl the earth once more into its abyss, the earth it so reluctantly left behind. The air, supposedly an enlivening and protective friend, suddenly races down upon us as a storm to smash us and choke us. The fire relentlessly attacks everything in reach which is flammable or meltable. These observations depress us when we realize how often we must make them after a great and irretrievable catastrophe. It elevates our hearts and minds, however, when we realize how man has armed himself against the elements, defended himself, and even used the enemy as his slave.

In such instances we reach the highest level of thought with a perception of what nature bears within itself as law and rule to impose on those unbridled, lawless forces. Although we have learned much about this, we can consider only the most obvious point here.

The intensified attraction of the earth (indicated by a rise in the barometer) is the force which regulates the state of the atmosphere and controls the elements; it resists excessive water formation and the strongest movements of air; it even seems to keep electricity in a state of perfect neutrality.

Lower barometric pressure, on the other hand, releases the elements; here we should first note that the lower region of the continental atmosphere has a tendency to flow from west to east. Moisture, rain showers,

waves, billows—mild or stormy, they all travel eastward, and where these phenomena are created along the way, they are born with the tendency to press eastward.

Here we will mention another point worth considering: after the barometric pressure has been low for a long time and the elements have grown unaccustomed to obeying, they will not return immediately to their bounds when the barometer rises. They remain on the same track for a time; the turbulence in the lower levels regains the desired balance *only gradually, long after the upper atmosphere has reached a quiet* resolution. Unfortunately we are also affected by this last period—coastal dwellers and sailors are especially hurt by it. The end of 1824 and the beginning of this year give the saddest evidence of this; westerlies and southwesterlies produce and accompany the most tragic happenings at sea and on the coast.

Once off in a general direction, our thinking hardly knows where to stop. We might be inclined to view the earthquake as earth's electricity unbound, the volcano as the element of fire aroused, and to relate these things to barometric effects. But empirical observation does not support this, for these movements and events seem to be localized, with some effect over a wider area.

Analogy

When seduced into venturing a larger or smaller scientific construct, we are well advised to look for analogies to test it. In following this advice here, I find the preceding description resembles the one I use in the *Theory of Color*.

In chromatics I oppose light and darkness to one another; these would never have any connection if matter did not intervene. Whether matter is opaque, transparent, or even alive, the quality of light and dark will manifest in it, and color in all its nuances will be created forthwith.

We have likewise put the *force of attraction* and its effect, *gravity*, on the one side, and the *force of warmth* and its effect, *expansion*, on the other; we have treated them as independent of one another. Between the two we put the atmosphere, empty of any so-called corporality, *and we see that what we call "weather" arises in accordance with the* effects of these two forces on the rarefied matter of the air. Thus the element in which and by which we live is organized in various but regular ways.

Recognition of Law

It can be seen that this is a highly complicated matter. In dealing with it, we think it right to start with its clearest aspect, i.e., the aspect

most frequently repeated under similar conditions, the one which points to a constant regularity. Here we must not allow ourselves to be confused by the fact that what we thought mutually productive and consistent may sometimes seem to deviate and contradict itself. This is especially important in cases like this, where cause and effect are so easily confused in the midst of such complexity, and where correlates are viewed as mutually determining. To be sure, we will assume a basic law of weather. But we will also pay close attention to the endless physical, geological, and topographical differences, so that we can understand deviations in the phenomena as far as possible. If we hold fast to the regularity we will always find ourselves led back to it by our observations; anyone who fails to recognize the law will doubt the phenomenon, for, in the highest sense, every exception is included in the rule.

Self-Examination

In working on a venture like the present essay, the author must never forget to test himself in a variety of ways. This is done best and most certainly by looking back into history.

Even if we consider only those researchers who strove to restore the sciences, we will find that each was forced to make do with what empirical observation provided. The sum of what was actually known left many a gap across its breadth; various scientists sought to fill these gaps by reason or the power of imagination, for every scientist seeks the whole. With the growth of empirical knowledge, these inventions of imagination, these premature conclusions of reason, were set aside; a pure fact replaced them, and the phenomena took on more and more reality and harmony. A single example will serve for all.

I well remember: from my earliest school days to the present, the great and disproportionate space between Mars and Jupiter has interested every observer, and produced a variety of explanations. We may recall the efforts made by Kant, the great philosopher, to reach some degree of satisfaction about this phenomenon.[5]

Here, if we may say so, a problem came to light—the light of day itself hid the fact that many small asteroids were circling one another, replacing a larger celestial body in the most extraordinary way.

Thousands of such problems may be found in the realm of scientific research; they would be solved more quickly if we did not so hastily dispose of them or obscure them by opinions.

Meanwhile, what we call *hypothesis* continues to assert its old claims, especially when it brings some movement in an apparently insoluble problem and puts us in a position to see things more easily. Such credit belongs to antiphlogistic chemistry:[6] the same subjects were dealt with,

but rearranged in a different order so that we could grasp them in a new way, and from a different angle.

In a similar vein, I have attempted to find a tellurian explanation for the principles governing our weather, and in some sense to ascribe atmospheric phenomena to the changing, pulsating gravity of the earth. Day by day I have come to feel the complete inadequacy of the notion that such constant phenomena as planets and moon cause a mysterious ebb and flow in the atmosphere. If I have simplified our concept in this regard, it is in the hope of bringing the time closer when we will discover *the true underlying principles of the matter.*

Although I am under no illusion that this explains and settles everything, I am still convinced that we should continue our research in this way, and look at the details of the matter as they emerge. This will bring us to a point I have neither imagined, nor can imagine; a point which will bring the solution of this problem and related ones.

Colors in the Sky

These colors correlate closely with meteorological conditions.

We must make careful note of the following observation, for it demonstrates the principle underlying every appearance of color in the atmosphere.

A turbid glass held before a dark background and illuminated from the front will appear bluish. The less turbid the glass, the bluer it will look; the least turbid glass will seem violet. Conversely, the same glass held before something bright will look yellow. The denser the glass, the redder it will seem, so that in the end even the sun will appear ruby red.[1]

The air, even at its clearest, is a vehicle for moisture and must therefore be considered a turbid medium. This is why the sky opposite the sun and around it looks blue: the darkness of space creates this effect through the veiling. This is also why mountains in the middle distance seem darker blue than those in the far distance.

On the highest mountain peaks the air will seem deep blue because of the purity of the atmosphere there; ultimately it will take on a reddish tinge. In the plains, where the air becomes increasingly dense and filled with turbidity, the blue will grow ever paler, finally vanishing and assuming a completely white appearance.

Seen through an atmosphere thick with haze, the sun and the bright area around it will seem to have a yellow-red to red color.

Before sunrise and after sunset, when the sun shines through the thick haze on the horizon, the clouds will be lit with a glow which is yellow or even red.

When there is a heavy layer of haze in the upper atmosphere the sun will appear blood red, as through a very turbid glass.

In the accompanying illustration the blue scale has been combined with the scale of yellow and red.[2] The former has only half its steps, but not even all these will be found in our part of the world. The latter contains the whole range, but the deepest red is rarely found here. In Italy it appears at the time of the sirocco.

Polarity[1]

Two needs arise in us when we observe nature: to gain complete knowledge of the phenomena themselves, and then to make them our own by reflection upon them. Completeness is a product of order, order demands method, and method makes it easier to perceive the concept. When we are able to survey an object in every detail, grasp it correctly, and reproduce it in our mind's eye, we can say that we have an intuitive perception of it in the truest and highest sense. We can say that it belongs to us, that we have attained a certain mastery of it. And thus the particular always leads us to the general, the general to the particular. The two combine their effects in every observation, in every discourse.

We will begin with some general notions.

Duality of the phenomenon as opposites:

We and the objects
Light and dark
Body and soul
Two souls[2]
Spirit and matter
God and world
Thought and extension[3]
Ideal and real
Sensuality and reason
Fantasy and practical thought
Being and yearning
Two halves of the body
Right and left
Breathing.

Physical experiment:

Magnet.[4]

Our ancestors admired the economy of nature. She was thought to have a practical character, inclined to do much with small means where

others produce little with great means. As mere mortals, we stand even more in admiration of the skill with which she is able to produce the widest variety of things while restricted to only a few basic principles.

To do this she uses the principle of life, with its inherent potential to work with the simplest phenomenon and diversify it by intensification into the most infinite and varied forms.

Whatever appears in the world must divide if it is to appear at all. What has been divided seeks itself again, can return to itself and reunite. This happens in a lower sense when it merely intermingles with its opposite, combines with it; here the phenomenon is nullified or at least neutralized. However, the union may occur in a higher sense if what has been divided is first intensified; then in the union of the intensified halves it will produce a third thing, something new, higher, unexpected.

Theory of Color[1]
Didactic Section

For Her Grace
Louisa
Duchess of Saxe-Weimar and Eisenach[2]

Your Grace:

Even if the content of the present work should not be entirely suited for presentation to Your Grace, and even if the most exacting scrutiny should find the treatment of the subject inadequate, these volumes are nonetheless entirely Your Grace's and have been dedicated to Your Grace since their earliest inception.

For if Your Grace had not been so kind as to turn your attention to an oral presentation on the theory of color and related natural phenomena, I would scarcely have found myself in a position to clarify much of this in my own mind, to pull together its scattered elements and, if not to perfect my work, then at least to bring it to a close.[3]

An oral presentation makes it possible to bring the phenomena directly before the viewer's eyes and to repeat the presentation of many subjects in different contexts. This is admittedly a great advantage denied the printed page. May it nonetheless please Your Grace to accept what can be communicated on paper as a reminder of those hours which will remain forever in my memory. By the same token I am always mindful of the debt of gratitude I owe to numerous friends and above all to Your Grace for the many favors shown me over the years and in particular at the most decisive moments of my life.

I remain respectfully,

Your Grace's Most Obedient Servant,

J. W. v. Goethe

Weimar
January 30, 1808

Preface

In a discussion on color it is natural to ask whether we should not first touch on the subject of light. Our response to this question will be brief and candid: so much has been said in the past about light, and in such varied forms, that it would seem ill-advised to reiterate these statements or duplicate what has often been done before.

In reality, any attempt to express the inner nature of a thing is fruitless. What we perceive are effects, and a complete record of these effects ought to encompass this inner nature. We labor in vain to describe a person's character, but when we draw together his actions, his deeds, a picture of his character will emerge.

Colors are the deeds of light, what it does and what it endures.[4] In this sense we can expect them to tell us something about light. Although it is true that colors and light are intimately related to one another, we must consider both as belonging to all nature. Through them nature in its entirety seeks to manifest itself, in this case to the sense of sight, to the eye.

Similarly, the whole of nature reveals itself to yet another sense. Let us shut our eyes, let us open our ears and sharpen our sense of hearing. From the softest breath to the most savage noise, from the simplest tone to the most sublime harmony, from the fiercest cry of passion to the gentlest word of reason, it is nature alone that speaks, revealing its existence, energy, life, and circumstances, so that a blind man to whom the vast world of the visible is denied may seize hold of an infinite living realm through what he can hear.

Thus nature also speaks to other senses which lie even deeper, to known, misunderstood, and unknown senses. Thus it converses with itself and with us through a thousand phenomena. No one who is observant will ever find nature dead or silent. It has even provided a confidant for the rigid body of the earth, a metal the least fragment of which tells us about what is taking place in the entire mass.[5]

No matter how diverse, enigmatic and intricate this language often seems, its elements remain forever the same. With gentle weight and counterweight nature balances the scales as they swing. "Here and there," "up and down," "before and after," are dimensions that emerge in the course of this weighing and serve to make specific the phenomena we meet in space and time.

We perceive these elements of movement and structure in a variety of ways: as simple attraction and repulsion, as the waxing and waning of light, as the motion of air, as vibration of solid bodies, as oxidation and reduction. All these, however, have the effect of dividing or uniting, of setting existence in motion and lending support to some form of life.

Observers have found an apparent imbalance in the effect of weight and counterweight and have tried to give expression to this relationship

as well. They have noted this principle in all things and given names to it: plus, minus; aggressive, resistant; active, passive; assertive, restraining; force, moderation; male, female. In this process a language, a set of symbols, has arisen which we may apply to like events in a metaphor, a closely related expression, a precisely suited word.

The main goals of the present volume are to extend the application of these universal terms, this language of nature, to the theory of color; to expand and enrich this language through the theory of color and the diversity of its phenomena; and thereby to help disseminate deeper insights among the friends of nature.

The work itself is divided into three parts. The first offers a theory of color in outline. There the many examples of color phenomena are categorized by general type, and the categories are presented in an order explained in the introduction. Here we must note however that, although we have relied on empirical evidence throughout, it has proven impossible to avoid some discussion of the theoretical views which serve as a basis for the arrangement and structure of our work.

An extremely odd demand is often set forth but never met, even by those who make it: i.e., that empirical data should be presented without any theoretical context, leaving the reader, the student, to his own devices in judging it. This demand seems odd because it is useless simply to look at something. Every act of looking turns into observation, every act of observation into reflection, every act of reflection into the making of associations; thus it is evident that we theorize every time we look carefully at the world. The ability to do this with clarity of mind, with self-knowledge, in a free way, and (if I may venture to put it so) with irony, is a skill we will need in order to avoid the pitfalls of abstraction and attain the results we desire, results which can find a living and practical application.

In the second part of the work we will undertake to lift the veil from Newton's theory, which by virtue of its power and authority has long obstructed an unprejudiced view of color phenomena.[6] We will take issue with a hypothesis to which our age still pays traditional homage even though it is now useless. If the theory of color is not to lag behind so many other more developed fields of science, as has been the case, its true nature must be made apparent and the old fallacies swept away.

The content of the second section may seem dry, although the tone of the discussion is perhaps too vehement and passionate. We will thus take the liberty of using a rather playful metaphor in preparation for those more serious matters and also in partial atonement for their vigorous treatment.

We may compare Newton's theory of color to an old castle originally laid out by the builder with youthful impetuosity and later expanded and furnished as required by time and circumstance. It was then gradually fortified and secured against strife and enemy attack.

His descendants and heirs proceeded in the same fashion. They were forced to enlarge the structure, joining here, adding there, extending it under the pressure of increasing internal need, external hostilities and various unexpected turns of fate.

All these strange parts and additions had then to be joined by an odd array of galleries, halls, and passageways. Damage was immediately repaired, whether inflicted by an enemy or the force of time. When necessary, moats were deepened, walls raised, the requisite towers, window bays and gunports provided. This great care and effort brought forth and perpetuated the preconception that the citadel was of great value, even though the arts of building and fortification had greatly advanced in the meantime and much better homes and fortresses were being built elsewhere. Chiefly, however, the old castle was accorded a place of honor because it had never fallen, because it had repelled so many attacks, frustrated so many enemies, and maintained its virginity intact. This name and reputation endure to the present day. No one notices that the old structure has become uninhabitable. We always hear of its wonderful durability and delightful fittings. Pilgrims wend their way to it, hasty sketches are circulated in all the schools, and the impressionable young are urged to pay homage to it. All the while the building stands empty, guarded only by a few aged soldiers who seriously consider themselves fully prepared for its defense.

Here, therefore, we are not speaking of a long-drawn-out siege or indecisive conflict. We discover this eighth wonder of the world to be an abandoned relic, near collapse. Without further ado we will begin to dismantle it from the roof down, so that at long last the sunlight can shine into that decayed nesting place of rats and owls, revealing to the eye of the astonished traveler its labyrinthine, incoherent design, its constricted, makeshift arrangement, the many things added by accident, artificially contrived, or pitifully patched together. Such a penetrating look is possible, however, only when wall after wall is razed, vault after vault tumbles, and the debris is removed as quickly as possible.

In the second part of our work we have undertaken the difficult task of demolition, of clearing the site where feasible while arranging the materials thus gained for reuse in a new edifice. If the enthusiastic commitment of all our energy and skill succeeds in leveling that bastion and creating space for our work, we will not fill it immediately with some cumbersome new building, but rather try to develop a beautiful series of diverse structures in its place.

The third section of our work[7] will be devoted to historical investigations and the work of earlier commentators. Previously we expressed the thought that the history of a person portrays that person; it is also

possible to say that the history of science is science itself. We can never recognize fully what is ours until we learn to recognize what our forebears possessed; we will never truly enjoy the merits of our own age if we do not know how to value the merits of ages past. It was impossible, however, to write or even prepare a history of color theory while Newton's dogma held sway. No group with aristocratic pretensions has ever looked down on outsiders with such insufferable arrogance as the Newtonian school has shown from the beginning in dismissing everything accomplished before its founding and beyond its confines. We are dismayed and indignant to find Priestley in his history of optics[8] (and so many others before and after him) portraying the advent of the supposed "decomposed ray of light" as the moment of salvation for the world of color, while raising his eyebrows at our predecessors who quietly trod the right path. It was they who left us a legacy of observations which we will not surpass in precision, and thoughts which we will not formulate more correctly.

An author who plans a history of some field of knowledge may be expected to provide us with information on how its phenomena gradually came to light and how it has been dealt with in fantasy, belief, opinion, and thought. To put all this into coherent form is extremely difficult, and the writing of history is always a problematic affair. Even with the most honest of intentions it is easy to fall prey to dishonesty; indeed, anyone who undertakes such a presentation declares from the outset that he will place some things in the light and leave others in the shadows.

Nonetheless, the author of the present work has long looked forward to such a task. As a rule, however, a concept stands fully before the mind's eye while its realization proceeds only in a piecemeal fashion. Thus we have had to resign ourselves to providing the materials for such a history rather than the history itself. These materials include translations, excerpts, our views and those of others, indications and hints, an anthology which may not satisfy every expectation but may merit respect for the earnestness and devotion that produced it. In any case it is our hope that such selected yet unsynthesized materials will be all the more acceptable to the thoughtful reader, for he may take pleasure in combining them as he will.

The third section, historical in its intent, does not complete our work however. We have therefore included a fourth section as a supplement containing revisions.[9] We have numbered our paragraphs chiefly as an aid in referring to these revisions. In publications of this sort a few points may be forgotten, a few must be omitted to avoid confusion, others may be discovered only later, and still others may require clarification and correction. As a result, additions, emendations, and cor-

rections are unavoidable. We have also taken this opportunity to append citations for our sources and to include a few essays on special topics (such as colors in the atmosphere) which arise from time to time in the main body of the discussion. Here they may be placed before the imagination in a unified way.

While the essay on colors in the atmosphere will take the reader into the world of nature at large, a second will seek to advance our technical knowledge by offering a detailed description of the instruments required for the future study of color.

Only the accompanying plates remain to be discussed. Here, to be sure, we find a reminder of the shortcomings and imperfections our work has in common with all other works of this kind.

A good play is only half present in the written text. The greater portion of it draws on the glitter of the stage, the personality of the actor, the power of his voice, the distinctiveness of his gestures, even the intelligence and favorable mood of the audience. This applies all the more to a work on natural phenomena. If the reader is to enjoy and make use of it, he must actually have nature before him, either in fact or in the activity of his imagination. It should be as though the writer were speaking in person; his text should be a directly visible demonstration of the phenomena as they occur naturally or artificially. Then all his commentary, clarification and interpretation will succeed in creating the effect of life.

The plates which often accompany such treatises offer an inadequate surrogate for this. An ongoing physical phenomenon, its forces radiating in every direction, cannot be contained in line drawing or indicated by a cross section. No one would dream of explaining chemical experiments with diagrams, yet similar experiments in physics are often explained in this way, for such diagrams have certain uses. Frequently, however, these diagrams depict only concepts. They work as symbolic aids, hieroglyphic modes of communication which gradually replace the phenomena, replace nature itself, and become more a hindrance than a help in the pursuit of true knowledge. We, too, have found it necessary to include such plates, but we have tried to arrange them so that the reader may feel confident in finding didactic and polemic applications for them. Certain plates may even be viewed as belonging to the supplementary apparatus mentioned above.

Lastly, then, we have only to direct the reader's attention to the work itself, and to ask a favor in advance which many an author has requested in vain and which the modern German reader grants with particular reluctance:

> *Si quid novisti rectius istis,*
> *Candidus imperti; si non, his utere mecum.*[10]

Introduction

Si vera nostra sunt aut falsa, erunt talia, licet nostra per vitam defendimus. Post fata nostrá pueri qui nunc ludunt nostri iudices erunt[11]

The desire for knowledge first stirs in man when he becomes aware of significant phenomena which require his attention. To sustain this interest we must deepen our involvement in the objects of our attention and gradually become better acquainted with them. Only then will we notice all manner of things crowding in upon us. We will be compelled to distinguish, differentiate and resynthesize, a process which finally leads to an order we can survey with some degree of satisfaction.

To achieve this even partially in any field of knowledge requires constant and rigorous effort. Therefore we find that many would prefer to dismiss phenomena with a general theoretical precept or a quick explanation without taking the trouble to study them in detail and achieve a knowledge of the whole over a longer period of time.

Until now there have been only two attempts to present and integrate color phenomena, the first by Theophrastus and the second by Boyle.[12] None will dispute the position of the present work as the third attempt in this direction.

Further information on this point will be found in the historical section of our work. Suffice it to say here that such a synthesis was inconceivable in the last century because Newton had based his hypothesis on a complex, secondary experiment,[13] one which required the creation of artificial relationships to connect it with other basic phenomena (those, at least, which could not be passed over in silence or simply dismissed). Thus these phenomena were placed in an uneasy position of subordination around this central point. An astronomer, for example, would have to behave in the same way if he decided arbitrarily to place the moon at the center of our planetary system. He would then be forced to make the earth, the sun, and the rest of the planets orbit the lesser body, and to explain away and conceal the erroneous nature of his initial assumption by using contrived formulas and conceptual models.

Let us now proceed by recalling what we stated in the preface. There we considered light as a given. Here we will do the same with the eye. We stated that nature as a whole reveals itself to the sense of sight—the eye—through color. Though it may sound a bit strange, we will now assert that the eye does not see shape as such, since brightness, darkness, and color operate together as the sole means for the eye to

distinguish among objects or parts of objects. Thus we construct the visible world out of these three elements, and in the process we also make possible the art of painting, an art capable of producing on canvas a visible world far more perfect than the real world.

From among the lesser ancillary organs of the animals, light has called forth one organ to become its like, and thus the eye is formed by the light and for the light so that the inner light may emerge to meet the outer light.[14]

Here we are reminded of the ancient Ionian school[15] which always placed a strong emphasis on the principle that only things of like nature may recognize one another. We also recall the words of a mystic in antiquity,[16] translated as follows:

Were the eye not of the sun,
How could we behold the light?
If God's might and ours were not as one,
How could His work enchant our sight?

None will dispute a direct relationship between light and the eye, but it is more difficult to think of the two as being simultaneously one and the same. We may clarify this by stating that the eye has within it a latent form of light which becomes active at the slightest stimulus from within or without. We can evoke dazzling inner images in the dark through the power of our imagination. In dreaming, we see objects as though in the clear light of day. When awake, we can perceive the slightest impression of light from without, and we even find that when the eye is struck a burst of light and color is seen.

Now, perhaps those used to proceeding in a systematic way will remark that we have yet to offer a definition of color. Again, we would prefer to put this question aside, and refer the reader instead to the body of our work where we have demonstrated in detail how color comes about. At present we can simply repeat our view that color is nature conforming to its own laws in relation to the sense of sight. We must also assume that a person possesses this sense and is able to recognize nature's effect on it—we cannot discuss color with one who is blind.

In order not to seem too anxious to avoid the issue, however, we will restate the above as follows. For the eye, color is an elemental natural phenomenon. Like every other phenomenon it manifests itself in division and opposition, combination and union, intensification and neutralization, infusion and diffusion, etc., and can best be observed and understood through these general principles of nature.

We do not expect everyone to subscribe to this way of thinking about these matters; those who feel at ease with it, as we do, will readily accept it. Nor do we wish to engage later in quarrels and battles to

defend it. For the discussion of color has always brought some considerable risk, a fact that inspired a predecessor to say that waving a *red flag before a bull will rouse him to anger, but any mention of color* at all will send the philosopher into a rage.

Now, however, to give some account of the work to which we refer, we must first of all show the distinction we have made between the various conditions under which colors may arise. We have found three ways in which they appear, three types of colors, or if you prefer, three distinguishable aspects of color.

We first looked at colors insofar as they are a property of the eye, dependent on effect and countereffect in the eye. We then turned our attention to colors as observed within colorless media or created by such media. Lastly, we took note of colors which were undeniably a property of external objects. We called the first type of colors physiological; the second, physical; and the third, chemical. The first are entirely ephemeral, the second are transient but always linger for a time, and the third may be held constant over long periods.

For the purposes of our didactic *discussion we made distinctions* within this natural order and attempted to keep them as clear as possible, yet we also succeeded in presenting the colors in a continuous series, connecting the ephemeral with the transient and both of these with the permanent. Thus we were able to move beyond the divisions so carefully drawn at first, and achieve a more comprehensive view.

There follows a fourth section where in general terms we have stated the results of our previous observations about colors as they occur under various specific circumstances. In this section we have, in fact, provided the outline for a later theory of color. For the moment we will take only a brief look ahead with the statement that light and dark, brightness and darkness, or, to use a more general formulation, light and non-light, are necessary for the production of color. The color we find emerging closest to light we term yellow; a second which arises closest to darkness we call blue. A perfectly balanced combination of these two colors in their purest form will produce a third color we will green. Each of the first two colors may also create a new phenomenon of its own when concentrated or darkened. They take on a reddish appearance which may be intensified to such a degree that the original blue and yellow become almost impossible to recognize. The highest degree of pure red may be produced, however, by uniting the two extremes of yellow-red and blue-red, especially in the physical colors.

This is an organic view of color phenomena and production. However, one may also assume the presence of red in addition to the blue and yellow specified above. Reversing the steps and mixing colors would then produce results similar to those reached through progressive intensification. The basic theory of color deals solely with these three

(or six) colors, which may be arranged into a circular pattern for the sake of convenience. The almost infinite variety of other shadings pertain more to applied uses, to the painter's technique or the dyer's, to life as a whole.

Another general trait of colors is that it is possible to think of them as consisting entirely of semilight or semishadow. This is why they produce a darkening, a grayness, when they are combined so that the character of one color cancels that of the other.

Our fifth section brings a description of the supportive relationship our theory of color would establish with other spheres of knowledge and activity. As important as this section may be, it is rather less successful because of its theme, although the thought that such connections cannot really be described until formed gives some consolation for the shortcomings of this tentative effort. Indeed, it is not yet clear how those we have sought to serve will accept what we have done here. Our intent has been to present them with something both pleasurable and useful. They may accept it, apply it, and develop it further; or they may reject it, discard it, and leave it to languish by the wayside. In the meanwhile we will continue in our discussion of what we believe and hope to have accomplished.

We believe we have merited recognition by the philosopher for our attempt to trace the phenomena to their origins where they simply appear, exist, and allow for no further explanation. Moreover the philosopher will welcome our arrangement of the phenomena in an order that is easy to survey, even if he does not fully approve of the order itself.

We hope we have gained a friend in the physician, particularly the specialist devoted to studying the eye, caring for its health, correcting its deficiencies and healing its diseases. He will find himself quite at home in the section on physiological colors and in the supplement touching on pathological colors. Through the efforts of those who even now are successful in their specialty we will surely see an extensive development of this basic topic in the theory of color, a topic which is perhaps the most important in color theory, yet one long neglected.

We should receive the most cordial reception from the physicist, since we have made it convenient for him to present the theory of color in the context of all other elemental phenomena, and apply the same language—in fact, almost the same words and symbols—as in his other areas of interest. To be sure, we have added somewhat to his burden as a teacher, for henceforth it will not be so easy to dismiss the chapter on color with a few brief paragraphs and experiments. Nor will it be so simple to go on serving up the usual meager fare without complaint from the student. In compensation, however, another advantage will emerge later. For although Newton's theory was easy to learn, its ap-

plication has produced insurmountable difficulties. Our theory is perhaps harder to grasp, but once grasped it requires nothing more, for it carries its application within itself.

The chemist who uses color to measure the less obvious properties of physical matter has traditionally encountered many problems with the terms and names applied to colors. Indeed, closer and more careful study has produced the view that colors are uncertain and deceptive indicators in chemical experiments. We nonetheless hope to restore them to a place of honor with our description and suggested terminology, and to awaken the conviction that something which develops, grows, moves, and is capable of change does not deceive, but in fact reveals the most delicate effects of nature.

Looking now further afield, we become apprehensive about having displeased the mathematician. Through a peculiar set of circumstances the theory of color has been forced to enter a realm where it does not belong, to appear before the judgment seat of the mathematician. This has happened because of its relationship to other laws of sight for which mathematics is appropriate. It was also a result of the fact that a great mathematician developed the theory of color. Having erred as a physicist, he concentrated the full force of his talent on giving his error the appearance of being logically consistent. An understanding of these two points will clear away any misunderstanding and persuade the mathematician to offer his help, particularly in developing the study of physical colors.

By contrast, our work must be especially welcome to the technician, to the dyer. In fact, those who have reflected on the phenomena of dyeing have been quite dissatisfied with the previous theory—they were the first to perceive the inadequacy of Newton's doctrine. For a great deal depends on the approach taken to a field of knowledge or a science, the gate by which one enters. Phenomena forcefully confront the true practitioner, the producer of goods, every day. He experiences the application of his ideas as profit or loss, he cares about the waste of time and money, and strives to make progress, to equal and surpass what others have done before him. He will be much quicker to feel the hollow and false qualities of a theory than the scholar who in the end will accept a cliché as valid currency, or the mathematician whose formula remains correct even after it ceases to be applicable to the intended subject. Since we found our own way to the theory of color from painting, from the esthetic coloration of surfaces, we have also provided something for which the painter may be thankful. In the sixth section of our work we have sought to determine the sensory and moral effects of color and thereby relate it more closely to its use in art. Much in this section and elsewhere remains merely a sketch, but any theoretical endeavor should do no more than outline the paths along which a deed

may wander with the touch of life until it bears fruit in keeping with the laws of nature.

Part One
Physiological Colors

1. It is appropriate to start with a study of physiological colors because they are wholly, or largely, a property of the observer, of the eye. These colors are the basis for our entire theory, and also reveal the principle of chromatic harmony about which there has been so much debate.[17] Until now, however, they have been considered inconsequential and random, an illusion and a defect. Physiological colors have been known from the earliest times, but since their fleeting quality could be neither caught nor held they were exiled to the realm of mischievous phantoms. In keeping with this they have received a wide variety of names.

2. Thus in Boyle they are called *colores adventicii;* in Rizzetti, *imaginarii* and *phantastici;* in Buffon, *couleurs accidentelles;* in Scherffer, illusory colors. Others call them optical illusions and visual deceptions. Hamberger terms them *vitia fugitiva* and Darwin calls them ocular spectra.[18]

3. We have called them physiological colors because they are a property of the healthy eye. We consider them innate conditions for sight, evidence of the living interaction between its inner nature and the outer world.

4. Immediately following this section we have added a discussion of pathological colors which offer a deeper insight into physiological colors, just as any abnormal state helps us to understand the normal.

I. Light and Dark As Sensed by the Eye

5. Depending on whether light or dark affects it, the retina is in one of two states, each the absolute opposite of the other.

6. With our eyes open in a completely dark room we sense a certain deprivation. Our organ of sight is left to itself, it withdraws into itself and loses the stimulating, fulfilling contact which unites it with the outer world and makes it whole.

7. When we turn our eyes to a strongly illuminated white surface they are blinded and for a time unable to distinguish less brightly illuminated objects.

8. Each of these extreme states affects the entire retina as indicated, and to this degree we are able to experience them only one at a time. In the first instance (§6) we found the organ completely relaxed and

receptive. In the second (§7) it was in a state of extreme tension and insensitivity.

9. The disparity is perceptible when we move rapidly from one state to the other, even where they are not radically different. For example, merely by moving from bright surroundings to slightly dimmer ones we can observe how such states persist for a time.

10. A person going from daylight into a dimly lit place is at first unable to discern anything. Gradually his eyes will recover their sensitivity. Good eyes do this more rapidly than weak ones, within only a minute as opposed to seven or eight minutes for the latter.

11. Strange errors in scientific observation may occur because the eye is insensitive to faint impressions of light following the transition from brightness to subdued light. For example, one observer whose eyes recovered slowly believed for a time that decaying wood does not luminesce at noon, even when placed in a dark room. One reason he missed the faint glow was that he routinely went from bright sunlight directly into the darkened room. Only later did he stay in the room long enough for his eyes to recover.

This may explain why Dr. Wall was scarcely able to see the electric gleam of amber during the day, even in a dark room.[19]

This is also why stars are invisible during the day, and why paintings are better viewed through a pair of hollow tubes.

12. A person who leaves a completely dark room and steps into a spot where the sun is shining will be blinded. One who goes from dim illumination into a light which is bright but not blinding will be able to observe every object more clearly and freshly. This is why a rested eye is always more sensitive to moderate effects.

Prisoners long held in darkness display such great retinal sensitivity that they can distinguish objects even in the dark (presumably a dimly illuminated darkness).

13. In the process of what we call "seeing" the retina is simultaneously in different—indeed, in opposite—states. Strong but not blinding illumination works side by side with absolute darkness. At one and the same time we perceive all the intermediate degrees of light and shadow, and all the distinct qualities of color.

14. In due course we intend to consider and note these elements of the visible world, and how our organ of sight responds to them. With this as a goal we will begin by considering the simplest type of form.[20]

II. BLACK AND WHITE FORMS AS SENSED BY THE EYE

15. When confronted by individual light and dark objects the retina behaves just as it does with light and dark in general. Light and dark put the whole eye into opposite states consecutively, but black and

white forms striking the eye together produce these states simultaneously.

16. A dark object appears smaller than a light one of the same size. From a distance let us view two round forms of the same diameter placed side by side, the one white on a black background and the other black on a white background. We will see the latter as about a fifth smaller than the former. If we enlarge the black form by a fifth, the two will seem equal in size.

17. Thus Tycho de Brahe[21] observed that the moon seemed to be about a fifth smaller in conjunction (the dark of the moon) than in opposition (the bright full moon). The first crescent moon appears to be part of a disk larger than that of the adjoining dark portion (often visible when the moon begins to wax). Black clothing makes a person look thinner than light clothing. Lights viewed behind the edge of an object make an apparent notch in the edge. A ruler behind which a candle is visible appears to have a nick in it. The rising or setting sun seems to make a notch in the horizon.

18. Black, as a representative of darkness, leaves the eye in a state of repose; white, representing light, stirs it to activity. From the phenomena discussed above (§16) we may conclude that the retina at rest and undisturbed is contracted, and occupies less space than when stimulated by the action of light.

Kepler states it well when he says: "Certum est, vel in retina causa picturae, vel in spiritibus causa impressionis exsistere dilatationem lucidorum" (*Paralip. in Vitellionem,* p. 220).[22] Father Scherffer makes a similar conjecture.

19. Nevertheless, either state induced in the eye by such a form continues to occupy space there and persists for a time even when the outer cause is removed. We scarcely notice this in daily life, for we seldom meet with violently contrasting forms. We avert our eyes from those that dazzle us. We look from one object to the next, and the succession of forms seems clear-cut. We do not observe that some residue of the first creeps into the one that follows.

20. At the moment of waking, when our eyes are especially sensitive, we can fix our gaze on the crossed bars of a window against the early morning sky, then close our eyes or look at something very dark. For a time we will continue to see a black cross against a light background.

21. On the retina each form occupies its own space which will be large or small depending on the distance of the form. When we shut our eyes just after glancing at the sun we will note with surprise how small the form of its afterimage seems.

22. But we may then open our eyes, turn toward a wall, and compare the phantom floating before us to surrounding objects: it will seem larger

when the distance to the surface of the wall is greater. An explanation for this phenomenon might be found in the rule of perspective that a small object nearby will hide a larger one further away.

23. The duration of this impression varies with the condition of the eye. Like the recovery time of the retina following the transition from bright illumination to darkness (§10), it is measurable in minutes and seconds. Indeed, we can now measure this much more precisely than when it was done by twirling a burning fuse which appeared as a circle to the observer's eye.

24. The energy of the light affecting the eye is also a factor. The form of the sun remains for the longest period while other more or less luminous bodies leave their traces for longer or shorter lengths of time.

25. These forms disappear gradually through a loss of both definition and size.

26. They shrink inward from the periphery; rectangular forms have been found to give the impression that the corners are becoming rounded, leaving an ever smaller circular form floating before us.

27. We may, as it were, bring such a form back to life on the retina after its impression is no longer perceptible; this is done by opening and closing our eyes, alternately stimulating and protecting them.

28. In eye disorders the persistence of forms on the retina for fourteen to seventeen minutes and even longer is a sign of extreme weakness in the organ, an inability to restore itself, just as a vision of things fervently loved or hated signifies not a sensory experience but a mental state.

29. If we look at a light gray surface while the impression of the window form described above is still present, the cross will appear light and the surrounding windowpane dark. In the previous case (§20) conditions were unchanged and thus the impression remained the same. Here, however, there is a reversal which draws our attention. Observers have recorded many instances of this.

30. Scientists conducting research high in the Cordilleras observed a bright glow around the shadows cast by their heads on the clouds.[23] This case belongs here because the scientists continued moving as they watched the dark form of the shadow, thus giving the impression that the bright image required by the eye was floating around the dark form. If we look at a black circle on a light gray surface and then shift our gaze the least bit we will see a bright glow hovering around the dark circle.

I have also had an experience of this sort. Seated on the ground, I spoke with someone standing at a distance against a gray sky. After looking at him intently for a long time, I shifted my gaze slightly and his head appeared to be surrounded by a brilliant light.

This is perhaps the place to record the phenomenon noted by strollers along dewy meadows at sunrise when they perceive a brilliance around their companions' heads. This brilliance may also be tinged with color because the phenomena of refraction are to some degree mixed in.

Similarly, it has been asserted that bright and partially colored circles could be seen around the shadows of balloons on the clouds.

Father Beccaria[24] performed several experiments on atmospheric electricity in which he sent paper kites aloft. A small luminous cloud of varying dimensions appeared around this device and even around a part of the string. It disappeared from time to time, and when the kite darted away the cloud was seen to float back and forth for a while in the spot where it had been. This sight, inexplicable to observers at the time, was the form of the dark kite retained in the eye and changed into a luminous form against the bright sky.

In optical experiments (especially chromatic ones) where bright white or colored lights are often used, particular care must be taken to prevent the lingering afterimage of an earlier observation from mixing with the one that follows, thus confusing and contaminating it.

31. The following explanation has been offered for these effects. The spot on the retina where the form of the dark cross fell should be thought of as rested and sensitive. It is more vigorously affected by a moderately illuminated surface than the remainder of the retina where the light from the window had fallen. Having been excited by so much more powerful a stimulus, the latter portion of the retina can only perceive the gray surface as dark.

32. This manner of explanation seems reasonably adequate for the present. In the observation of effects to be discussed later, however, we will find it necessary to look to a higher level for the sources of this phenomenon.[25]

33. The eye of a person not asleep reveals its living quality largely through its constant need to alternate between different states; at its simplest this consists of moving from dark to light and back again. The eye cannot and will not remain fixed for even a moment in a particular state determined by some object. It is instead compelled to a form of opposition: setting extreme against extreme and intermediate against intermediate, it quickly merges opposites and strives to achieve a whole, both successively and simultaneously in time and space.

34. Perhaps the extraordinary pleasure we feel at the skillful use of chiaroscuro in black and white pictures and similar artistic works comes largely from our simultaneous perception of a whole. Otherwise this whole is more sought after than achieved by our eye, and found only in sequence. Regardless of the degree to which it is attained it can never be held fast.

III. GRAY SURFACES AND FORMS

35. A great many chromatic experiments require moderate light. We can readily produce this by employing surfaces which are gray to some degree; hence we must familiarize ourselves with gray. In doing so it is hardly necessary to note that in many instances a shaded or dimly lit white surface may be considered gray.

36. Since a gray surface lies between the extremes of light and dark, a phenomenon introduced earlier (§29) may provide a convenient experiment.

37. Let us hold a black form against a gray surface and continue looking at the surface when the form is removed. The space previously occupied by the form will appear much brighter than the surrounding area. We may also use a white form; after it is removed the space will seem darker than the rest of the surface. In either case when our eyes scan the surface the form will also move back and forth.

38. A gray form on a black background will seem much lighter than the same form on a white background. If we view them together we will have difficulty convincing ourselves that the two forms are the same shade of gray. We may infer that in this instance we have once again recognized the retina's great vitality and the silent contradiction every living thing is moved to express when presented with any specific state. Thus inhaling presupposes exhaling and vice versa; each systole presupposes its diastole.[26] Here, too, it is the eternal rule of life which is asserting itself. When offered something dark the eye demands something bright; it demands darkness when presented with brightness. Through this very fact it demonstrates its living quality, its right to take hold of an object, by bringing forth out of itself an element which is the opposite of the object.

IV. THE BLINDINGLY BRIGHT COLORLESS FORM

39. Looking at a blindingly bright form which is completely without color will leave a strong and lasting impression. The gradual fading of this impression will be accompanied by the phenomenon of color.[27]

40. Let us make a round aperture about three inches across in the window shutter of a darkened room; it should be possible to open and close the aperture at will. We can then allow sunlight to enter so that it shines through the aperture onto a sheet of white paper. After gazing steadily at the illuminated spot from a distance we may close the aperture and look toward the darkest part of the room. We will observe a round image floating before us, one which seems bright and colorless (or tinged slightly yellow), while the rim will immediately appear to have a purple cast.

It takes some time for this purple color to spread inward and cover the whole circle, finally displacing the bright center fully. When the entire circle has turned purple the rim will begin to turn blue; the blue will gradually work its way in to take the place of the purple. After the image has become altogether blue the rim will turn dark and colorless. It takes a long while for the colorless rim to replace the blue entirely and render the whole area colorless. The image will then disappear slowly. It does so by simultaneously weakening in intensity and shrinking in size. Here we may once again observe how the retina gradually recovers from a forceful outer impression through a succession of alternating reactions (§§25, 26).

41. With my own eyes I have found the following relative times for this effect (verified by several repetitions of the experiment):

After gazing at the blindingly bright form for five seconds and then shutting the aperture, I observed the apparent form with its color hovering before me. Thirteen seconds later it appeared entirely purple. It then took twenty-nine seconds for it to turn completely blue, and forty-eight to appear before me without any color at all. By blinking my eyes I revived the form repeatedly (§27) so that it took seven minutes to disappear.

Other observers will find these times to be shorter or longer depending on the strength or weakness of their eyes (§23). This variable aside, however, it would be of great interest if a specific mathematical ratio could be found in these observations.

42. In the very process of turning our attention to this odd phenomenon, however, we become aware of a new modification in it.

After receiving the above impression of light and then turning toward a light gray object in our dimly illuminated room, our eye will again see an image hovering before it—this time a dark one which gradually develops a green rim. Like the purple border in the last example, this green border will spread inward to cover the entire disk. After this we will observe a muddy yellow which, like the blue in the previous experiment, will fill the disk and finally yield to a colorless tone.

43. These two experiments may be combined by placing a black surface next to a white one in a dimly illuminated room and looking from one to the other as long as the eye retains the impression of the light. When we do this we will find alternating images in purple and green, and then the rest of images in turn. After some practice the two opposite colors may be seen at the same time by bringing the floating image to where the surfaces come together. This is easier when the surfaces are far enough away to make the spectral images seem larger.

44. Once, toward evening, I found myself in a smithy just as the glowing metal was laid on the anvil. After gazing intently at this activity for a time, I turned and happened to look into the open doorway of a

coal bin. At that moment an enormous purple form floated before my eyes; when I glanced over at a light-colored wooden wall the phenomenon appeared half in green, half in purple depending on whether the background was light or dark. At the time I made no note of how this phenomenon faded.

45. The phenomena associated with the fading of an extremely bright bounded form also occur when the entire retina has been blinded by light. The purple color seen by those who have been blinded by snow belongs in this category, as does the uncommonly beautiful green color seen in dark objects after we gaze at a sheet of white paper lying in the sun. A more exact investigation of these phenomena will await the younger researcher whose eyes can still bear some hard use for the sake of science.

46. Here we should also mention the letters printed in black which appear red when viewed during twilight. Perhaps, too, it is appropriate to include here the story that drops of blood appeared on the table where Henry IV of France sat to play dice with the Duke of Guise.

V. COLORED FORMS

47. We first observed physiological colors created by the fading image of a colorless, blindingly bright form, or during the recovery of the eye after colorless light has blinded it. We will find analogous phenomena when the eye is presented with a colored form. Here we must keep in mind what we have already learned.

48. Impressions made by colored forms remain in the eye like those made by colorless forms. The former, however, show more clearly the vigor of the retina as it responds to the need for opposition and forms a whole by adding the opposing element.

49. Let us hold a small piece of brightly colored paper or silk against a moderately illuminated white background, look steadily at the small colored surface for a time, and then remove it without shifting our gaze. A spectral image in a different color will appear against the white background. We may also leave the colored paper in place and look at a different spot on the white background to observe the appearance of this other color, for it arises from a form which now belongs to the eye.

50. As a quick aid to finding the colors produced by this activity of opposition we may refer to the illustration of the color wheel in our text.[28] This wheel conforms fully to nature in its arrangement, and will help in the present discussion because the colors placed diametrically opposite one another on the wheel are those which demand each other in the eye as complements. Thus yellow demands violet; orange, blue;

purple,[29] green; and vice versa. Thus each gradation requires its reciprocal, the simpler color requires the more complex, and vice versa.

51. Examples of this occur more often in daily life than we might think; indeed, the attentive observer will see these phenomena everywhere. We may contrast this with the fact that they have been considered transient defects when noted by the uneducated portion of the populace or by our ancestors. These effects have even roused anxiety in those who fear they signal the beginning of an eye disorder. Here we may mention a few representative examples of these phenomena.

52. On one occasion I stopped at an inn toward evening. Presently there entered an attractive young woman with a radiantly white face and black hair who wore a scarlet bodice. From a distance I looked at her intently in the dim twilight. When she left I saw on the white wall opposite me a black face surrounded by a bright glow; the apparel of the utterly distinct figure appeared in a beautiful sea green color.

53. Half-length portraits with colors and shadings reversed from nature are frequently used in optical experiments. After gazing at them for a time you will have the experience of seeing an afterimage of the figure about as it would be in nature. Indeed, this is proper, for it agrees with what we observed empirically; in the above example a black woman wearing a white scarf would have produced a white face surrounded by black. Not everyone, however, will succeed in seeing the details of the afterimage created by these illustrations as they are usually quite small.

54. I am convinced that these phenomena provide an explanation for one observation previously noted with interest by scientists.

It is said that on summer evenings certain flowers appear to sparkle, phosphoresce, or radiate a momentary light. Some observers describe these occurrences in more exact detail.

I had often sought to experience this for myself, even contriving several experiments in an attempt to produce it.

On the evening of June 19, 1799, I was strolling through the garden with a friend[30] just as twilight was passing into cloudless night. We distinctly saw something flamelike appear close to some oriental poppies, a flower redder than any other. We stood in front of the plants and observed them closely but were unable to see anything more; at last we succeeded in repeating the effect at will by walking to and fro while looking at them sideways. It became evident that this was a phenomenon of physiological color and that the apparent flashing was really the afterimage of the flower in the required blue-green color.

Looking directly at a flower will not cause this phenomenon, although it will appear when the gaze wanders. Viewed obliquely, however, the flower produces a momentary double image in which the afterimage is seen just next to and touching the actual form.

In the dim light of dusk the eye is completely rested and receptive, while the color of the poppy is strong enough to maintain its full effect in the twilight of midsummer. Thus it can call forth a complementary image.

I am convinced that it is possible to raise this phenomenon to the experimental level and create the same effect with paper flowers.

For the present, if you wish to develop the ability to observe this in nature make it a practice on garden walks to stare at brightly colored flowers and then glance immediately at the sand-covered path. You will then see the path strewn with flecks in the opposite color. This experiment works under cloudy skies, but can also be done in the most brilliant sunlight. The strong illumination heightens the color of the flower and enables it to evoke the complementary color vividly enough to be visible even in extremely bright light. Peonies bring forth beautiful green spectral images in this way, while calendulas produce lively blue ones.

55. A color reversal always occurs in experiments where colored forms affect limited portions of the retina, and also when the entire retina is affected by a single color. We can demonstrate this to ourselves by covering our eyes with a piece of colored glass. After looking for a time through a piece of blue glass and then removing it, we will find that to the naked eye the world will appear as though filled with sunlight, even if the day is gray and the surroundings autumnal and without color. Similarly, when we remove a pair of green-tinted glasses we will see the objects around us irradiated with a reddish sheen. I am therefore led to believe that it is inadvisable to use green glass or green paper to protect the eyes, for any fixed color does violence to the eye and forces that organ to assert its opposition.

56. Thus far we have observed the production of complementary colors in sequence on the retina, but it remains to be demonstrated that this predictable reaction may also occur simultaneously. When a colored form is impressed on one part of the retina the rest of the retina will promptly tend to produce the corresponding color as noted above. If we continue with our earlier experiment and look, for example, at a piece of yellow paper against a white surface we will find the rest of the eye predisposed to produce violet on the colorless surface. Admittedly the small amount of yellow will not be strong enough to create the effect plainly, but when we put a piece of white paper against a yellow wall we will see the paper overlaid with a violet cast.

57. Even though these experiments may be done with any colors, green and purple are especially suitable because of their ability to elicit one another with striking effect. We will find frequent instances of this in everyday life. When a piece of green paper is viewed through striped or flowered muslin, the stripes or flowers will seem reddish. Likewise,

a gray house seen through green slats appears reddish. The purple cast of a turbulent sea is also a complementary color. The illuminated portion of the waves appears in green (its own color) while the shadowed portion appears in purple (the complementary color). The random orientation of the waves toward the eye produces the effect as a whole. Objects outside will appear in the complementary color when viewed through an opening in red or green curtains. These phenomena will be visible everywhere to the alert observer, even to the point of becoming disagreeable.

58. We have seen these phenomena as they occur together, but we may also find them occurring in succession. If we hold a small piece of bright orange paper against a white surface and look at it carefully we will hardly be able to see the complementary blue on the rest of the surface. We may, however, remove the orange paper, causing the blue afterimage to appear in its stead; when the afterimage is fully in place a reddish yellow sheen will spread like lightning over the rest of the surface, giving a vivid demonstration of the creative force of necessity in this systematic principle.

59. Complementary colors not present in the outer world readily appear with and after the color that calls them forth. They are also heightened when part of our surroundings. The grass scattered among gray limestone pavement in a courtyard seemed to take on an immeasurably beautiful green tone in the barely perceptible reddish light cast on the stones by the evening clouds. By contrast, while walking through a meadow under moderately bright skies and with nothing but green around us, we will often see the tree trunks and paths agleam with a reddish light. This hue frequently occurs in paintings by landscape artists, especially watercolorists. Apparently they see it in nature, imitate it unconsciously, and find their works criticized later as unnatural.

60. These phenomena are of great importance: they give us an indication of the laws of vision and provide a necessary introduction to our further consideration of colors. The eye exhibits an exacting need for wholeness in this connection; it completes the circle of colors within itself. In the violet demanded by yellow as its complement we find red and blue, in orange lie yellow and red, to which blue responds; green unites blue with yellow and requires red; and so on through each shading of the most varied combinations. Earlier observers have already noted that we must presuppose three primary colors in this context.

61. When the elements forming a whole are still discernible within it we may rightly speak of it as a harmony. After exploring the entire round of our observations and returning to the beginning we will discuss how the principle of color harmony may be derived from these phenomena, and how these properties alone give color the ability to serve an esthetic purpose.

VI. COLORED SHADOWS

62. Before proceeding, however, we must note some extraordinary instances of this set of colors which give evidence of their vitality by requiring one another. Let us turn our attention to colored shadows. In introducing this subject we will begin with a consideration of colorless shadows.

63. A shadow cast by full sunlight on a white surface gives no sensation of color. It seems black or, in the presence of a counter-illumination capable of penetrating to the shadow, weaker, half-lit, gray.

64. Two conditions are required for colored shadows: first, that the light creating the shadow somehow tinge the white surface with color, and second, that a light from the opposite direction deliver a certain amount of illumination to the shadow.[31]

65. As a demonstration we may set a low-burning candle on a sheet of white paper placed in the evening twilight. We may then hold a pencil up between it and the fading daylight so that the shadow cast by the candle is lit but not obliterated by the weak daylight; this shadow will appear in the most beautiful blue.

66. We will recognize immediately that the shadow is blue, but only by looking closely will we conclude that the white paper acts as a reddish yellow surface which causes the eye to require this blue.

67. For every colored shadow we must therefore assume that a color has been cast on the surface across which the shadow falls. On careful observation we will be able to discern this color clearly. First, however, let us do the following experiment as a convincing demonstration of this.

68. At night let us light two candles, place them opposite one another on a white surface, and hold a thin rod up between them so that two shadows are created. We may then take a piece of colored glass and hold it in front of one candle so that a color is cast across the white surface. The complementary color will immediately appear in the shadow created by the colored candlelight and illuminated by the other candle.

69. Here an important consideration arises, one to which we will often return. Color itself has a quality of darkness (σκιερόν); Kircher is therefore correct when he calls it *lumen opacatum*.[32] Being related to darkness, color tends to unite with it, to become visible to us in darkness and through darkness whenever given the opportunity. Later we will discuss the origins and ramifications of the phenomenon touched on in colored shadows.

70. Let us find the moment during twilight when the light from the sky still casts a shadow not entirely obliterated by candlelight, so that a double shadow is produced, one cast by the candle toward the twilight

and the other cast by the twilight toward the candle. The first shadow will be blue whereas the second will be a bright yellow. This bright yellow is nothing but the reddish yellow color shed over the entire piece of paper by the candlelight and made visible in the shadow.[33]

71. The above experiment with two candles and colored glass will offer convenient proof of this. The incredible facility with which a shadow takes on color will be dealt with later when we examine the subject of reflections more thoroughly, and also at other points in our discussion.

72. Thus it would be easy to find the cause of colored shadows, a task which presented earlier observers with such difficulty. Henceforth, if we note colored shadows we need only observe the color tinging the surface upon which they appear. Indeed, we may consider the color of the shadow a chromatoscope of the illuminated surface, since we can assume that the surface is tinged with a color complementary to that of the shadow; we will invariably find it upon closer examination.

73. These colored shadows, previously the cause of much bewilderment, are now easily understood. Because they were principally observed out-of-doors and most often seemed blue, they were attributed to a certain hidden property of blue in the air which supplied a blue coloration. We can show that no blue light or reflection of any kind is needed to create the colored shadow if we conduct our candlelight experiment indoors on a gray, overcast day or even behind drawn white curtains in a room where not the least amount of blue is to be found. Under these conditions the blue shadow will simply appear in an even more beautiful way.

74. In his description of a trip on Mont Blanc, Saussure[34] says:

> A second note of some interest concerns the colors of the shadows which, despite the closest scrutiny, we never found to be dark blue, even though this had often been so on the plain. On the contrary, out of fifty-nine observations we saw yellow once, pale blue six times, no color or black eighteen times, and pale violet thirty-four times.
>
> Some physicists postulate that these colors arise more from random vapors dispersed in the air which lend their peculiar hues to the shadows, not from a fixed color of the air or the reflected color of the sky. These observations appear to favor this view.

We will now find it simple to make sense of the observations cited by de Saussure.

At that great altitude the atmosphere was largely free of haze. The sun shone full strength on the white snow so that this seemed absolutely white to the eye. Here they saw the shadows as completely without color. When the air was a bit hazy and the snow took on a yellowish hue as a consequence, violet shadows resulted. Indeed, these were the

most frequently observed. They also saw bluish shadows, but less often, and the pale hue of the blue and violet shadows may be attributed to the bright, glistening surroundings which diminished the intensity of the shadows. Only once did they see a yellowish shadow. As noted above (§70), this is a shadow cast by a colorless counter-illumination, and filled in by a primary light which is colored.

75. Once, on a winter's journey in the Harz Mountains, I made my descent from the Brocken as evening fell.[35] The broad slope above and below me was snow-covered, the meadow lay beneath a blanket of snow, every isolated tree and jutting crag, every wooded grove and rocky prominence was rimed with frost, and the sun was just setting beyond the Oder ponds.

Because of the snow's yellowish cast, pale violet shadows had accompanied us all day, but now, as an intensified yellow reflected from the areas in the light, we were obliged to describe the shadows as deep blue.

At last the sun began to disappear and its rays, subdued by the strong haze, spread the most beautiful purple hue over my surroundings. At that point the color of the shadows was transformed into a green comparable in clarity to a sea green and in beauty to an emerald green. The effect grew ever more vivid; it was as if we found ourselves in a fairy world, for everything had clothed itself in these two lively colors so beautifully harmonious with one another. When the sun had set, the magnificent display finally faded into gray twilight and then into a clear moonlit night filled with stars.

76. One of the most beautiful examples of colored shadows may be observed when the moon is full. It is possible to find a perfect balance between the light of a candle and that of the moon; both shadows are formed with equal strength and clarity so that the two colors are in complete equilibrium. The surface should be placed in the light of the full moon with a candle at an appropriate distance a little to one side; an opaque object should then be held in front of the surface. A double shadow will result: the one cast by the moon and lit by the candle will seem an intense red-yellow, while the one cast by the candle and lit by the moon will appear in the most beautiful blue. The area where the two shadows meet and merge will be black. There is no more striking demonstration of the yellow shadow. The close proximity of the blue shadow and intervening black shadow make the phenomenon all the more attractive. When we look at the surface for a long time the blue required as a complement by yellow will impose its own demand on the yellow which produced it; it will intensify the yellow and force it into the yellow-red. This in turn will bring forth its opposite, a shade of sea green.

77. Here it should be noted that it takes some time to produce the

complementary color. Before the complementary color will appear vividly the retina must be affected fully by the color that calls it forth.

78. Sunlight shining into a submerged diving bell will lend a purple cast to everything it strikes (the reason for this will be indicated later). The shadows, on the other hand, will look green. The phenomenon I observed on the top of a mountain (§75) is found by the diver deep beneath the sea, and thus nature is entirely at one with itself.

79. Here we will add a few observations and experiments which interpose themselves, in effect, between the section on colored forms and that on colored shadows.

On a winter's evening let us cover the inside of a window with a white paper blind having an opening in it through which the snow on a neighboring roof may be seen. When a candle is brought into the room at twilight the snow will appear blue through the opening. This is because the candlelight lends a yellow cast to the paper. Seen through the opening the snow acts as a shadow lit by a counter-illumination or, if you prefer, as a gray form on a yellow surface.

80. Let us close with another interesting experiment. If we take a rather thick sheet of green glass and place it so that it reflects a window with crossbars, we will see a double image: the image reflected from the bottom surface of the glass will be green while the image from the top surface will appear to have a purple cast, although it should be colorless.

We may do this experiment quite nicely with a watertight container having a mirrorlike bottom. We can begin by filling it with water to demonstrate colorless images and then produce colored images by tinting the water.[36]

VII. LIGHTS PRODUCING A WEAK EFFECT

81. Energetic light seems pure white; it makes this impression even when blinding in the highest degree. Light which does not work with full force may also remain colorless under some circumstances. Several scientists and mathematicians have attempted to measure the degrees of intensity in light: Lambert, Bouguer, Rumford.[37]

82. We soon discover, however, that color phenomena accompany weaker lights because such lights behave like gradually fading forms (§39).

83. Any light has a weaker effect when its energy is somehow diminished or when the eye lapses into a state which renders it unable to perceive the effect adequately. Phenomena resulting from diminished energy may be termed objective phenomena and are properly found among the physical colors; here we will mention only the transition of hot iron from glowing white to glowing red. Similarly, we find that even

at night candles seem redder to us as their distance from our eye increases.

84. At night the light from a nearby candle acts as a yellow illumination. We may observe this in its effect on other colors. In the nighttime pale yellow is scarcely distinguishable from white, blue resembles green, and a rosy hue looks like orange.

85. By twilight the candle gives a vivid impression of yellow illumination, a fact best shown by the blue shadows called forth in the eye.

86. A strong light can stimulate the retina to such an extent that it is unable to discern weaker lights (§11). When it does discern them, they appear to be colored. Therefore candlelight looks reddish by day; it behaves like a fading light. In fact, if we concentrate on looking at a candle by night it will seem to become redder and redder.

87. On the other hand some lights with a weak effect, like the moon on a clear night, make a white or, at most, a pale yellow impression on the retina. Rotting wood even has a somewhat bluish glow. These matters will be dealt with again later in our discussion.

88. If a candle is set beside a white or grayish wall at night, a considerable area of the wall will be illuminated by the light radiating from this central point. When we stand at a distance and view the circle thus created, the border of the illuminated area will appear to be surrounded by a yellow ring which is red-yellow at its outer edge; our attention is thus drawn to the fact that when light fails to affect us with its greatest energy, either directly or by reflection, it will seem yellow, reddish, or even red to the eye.[38] This brings us to the subject of the halos often seen around luminous points.

VIII. SUBJECTIVE HALOS[39]

89. Halos can be classified as either subjective or objective. The latter will be dealt with in the section on physical colors; only the former belong here. Subjective halos may be differentiated from objective ones by the fact that they disappear when the luminous object producing them on the retina is hidden from view.

90. Earlier we noted how a luminous form makes an impression on the retina and becomes larger there. But this is not the full extent of this effect. The luminous form acts not only as form, but also, beyond its own bounds, as energy; it spreads from the center to the periphery.

91. That such a nimbus around the luminous form is brought forth in our eye can best be observed in a dark room by looking at a small hole in the window shutter. This bright form will be surrounded by a nebulous round glow.

Once, while journeying in an overnight carriage, I observed just such a nebulous glow rimmed with yellow and yellow-red when I opened my eyes at daybreak.

92. Halos appear most vividly when the eye is rested and sensitive; they are also easily seen against a dark background. These two facts explain why we see them so strongly if we wake in the night and a light is brought to us. Both conditions were also present when Descartes[40] noted such brightly colored halos around a light after having slept on shipboard.

93. A light must be moderately bright, not blinding, if it is to create a halo in the eye; in any case, a halo formed by a blinding light would be impossible to observe. We see a gleaming halo of this sort around the image of the sun reflected from the water's surface to the eye.

94. Precisely seen, the border of such a halo is enclosed with a yellow fringe. However, even here the energetic effect noted above does not cease, but seems to continue moving outward in successive rings.

95. There are many instances which suggest a circular action of the retina, whether produced by the rounded shape of the eye itself and its various parts or by some other cause.

96. A small amount of pressure applied to the inner corner of the eye will make light or dark rings appear. Even without pressure it is often possible to observe a succession of such rings at night, one arising from the other, one being absorbed by the other.

97. We have already noted a yellow border around the area of a white wall illuminated by a nearby candle. This would be a type of objective halo. (§88)

98. We may conceive of subjective halos as the conflict of light with a living surface. Out of the conflict between what moves and what is moved there arises an undulating motion. We may use the example of ripples spreading on water as a metaphor. A stone dropped into water pushes the water in every direction; the effect reaches a peak, subsides, and then goes to an opposite extreme under the surface. It continues, culminates again, and thus the circles repeat. We may recall the concentric rings which appear in a goblet of water when we attempt to produce a tone by rubbing the edge; we may also think of the intermittent pulsations created when the sound of bells dies away. Thus in imagination we approximate the process which may take place on the retina when it receives the impression of a luminous object (except that the retina, being alive, already has a certain circular quality in its structure).

99. The bright circular area appearing around a luminous form is yellow edged in red, followed by a greenish ring surrounded by a red border. This seems to be the usual phenomenon with luminous bodies of a certain size. These halos become larger as one moves further from the luminous form.

100. The eye, however, may also see halos as extremely tiny and manifold when the impetus is small and powerful. This can best be demonstrated with gold glitter lying on the ground in direct sunlight. In these cases the halos appear in multicolored rays. The appearance of color created in the eye by the sun seen through foliage belongs in this category as well.

Pathological Colors
A Supplement

101. We are now familiar enough with physiological colors to differentiate them from pathological colors. We recognize the phenomena exhibited by the healthy eye and needed to reveal its full life and activity.

102. A similar indication of organic and physical laws is provided in phenomena related to illness, for whenever an individual living being departs from its form-giving principle it will strive throughout its life to return to that principle, always in an orderly way. The entire course of its existence makes us aware of those fundamentals from which the world sprang and by which it is preserved.

103. Here we will begin by mentioning a remarkable condition found in the eyes of many. Since a deviation from the usual way of seeing colors is symptomatic for this condition, it is probably right to include it in the section on pathological colors. However, because it is systematic, occurs frequently, may involve several members of the same family, and is apparently impossible to correct, we will be justified in placing it at the boundary between the physiological and the pathological.

104. I was acquainted with two people afflicted with this condition, neither over twenty years old. The eyes of both were blue-gray, and in daylight or candlelight both had excellent near and far vision. On the whole, the way they saw colors was completely consistent.

105. They agree with the rest of us in identifying the colors white, black and gray. They both saw white as unadulterated. One of them said he noticed a brownish cast in black and a reddish one in gray. In general they seem discriminating in their sensitivity to the gradations of light and dark.

106. They appear to see yellow, red-yellow, and yellow-red as we do; in the latter case they stated that they saw the yellow as though it were floating over the red like a glaze. Carmine which had dried and caked in the bottom of a saucer they called red.

107. Now, however, a startling difference emerges. When the carmine is painted lightly with a damp brush over the white surface of the saucer they will associate the light color thus created with the color of the sky and call it blue. When they are then shown a rose they will also call it

blue. In every test we devise they will be unable to distinguish light blue from a rose color. Without exception they confuse rose, blue, and violet; apparently they can tell these apart only by the fine differentiations between lighter and darker colors or brighter and duller ones.

108. Furthermore, they are unable to distinguish green from dark orange, and especially from reddish brown.

109. A random conversation with them about objects at hand will lead to great confusion and make us doubt our own sanity. By taking a somewhat systematic approach, however, we will come closer to understanding the order in this chaos.

110. As we saw above, they have fewer colors than we, hence the confusion between the various colors. They say the sky is rose and the rose blue, or vice versa. The question now arises: do they see both as blue or as rose-colored? Do they see green as orange or orange as green?

111. This strange puzzle resolves itself if we assume they see no blue, but see in its stead a dilute purple, a rose color, a light pure red. For the moment we may picture this solution symbolically as follows.

112. Let us eliminate blue from our circle of colors; then blue, violet, and green will be gone. Pure red will be extended to replace the first two and where it rejoins yellow it will substitute for green by producing orange again.

113. Because we believe this approach offers a convincing explanation, we have given the name "acyanoblepsia" to this peculiar deviation from normal vision. As an aid to clarification we have drawn and colored several illustrations for this and later intend to add further details in the description accompanying these drawings.[41] Also included is a landscape which has been colored according to the way these people apparently see objects in nature: the sky a rose color with foliage in shades from yellow to brown-red, like a landscape we might see in autumn.[42]

114. We will now discuss disease-related disturbances in the retina, as well as those of an accidental, unnatural or rare kind, in which the eye may be disposed to see light where no external light is present. A discussion of galvanic light will be reserved for later.

115. When our eye is dealt a blow we have the impression that sparks flash out. Moreover, in certain physical states, especially those of heated blood and excitability, we can call up an unbearable, dazzling light by pressing on our eye, gently at first and then with increasing force.

116. After a cataract operation the patient will experience pain and a burning sensation in his eyes, often accompanied by the impression of fiery flashes and sparks. These sometimes last one to two weeks or until the pain and burning have subsided.

117. One person with an earache saw sparks and balls of light when the pain was felt.

118. Those suffering from worms often experience peculiar symptoms of the eye: sometimes fiery sparks, sometimes specters of light, sometimes terrifying shapes they cannot be rid of, and sometimes double vision.

119. Hypochondriacs frequently see black shapes like threads, hairs, spiders, flies, or wasps. These symptoms also appear at the onset of degenerative blindness. Many see tiny semitransparent tubes, shapes like insect wings, or small bubbles of water in various sizes which float downward when the eyes are raised and sometimes cohere like frog spawn. At times these bubbles seem perfect spheres and at times lenticular.

120. In the previous cases light was produced without any external light; these forms likewise appear in the absence of any external form. Some are transitory and some last a lifetime. Color will occasionally accompany these states, for in many instances hypochondriacs see narrow yellow-red streaks, often with increased frequency and intensity *in the morning or on an empty stomach.*

121. We are already familiar with the physiological phenomenon that the impression made on the eye by some form will persist for a time (§23). However, the excessive persistence of such an impression may be considered pathological.

122. The weaker the eye, the longer it will retain the image. The retina is unable to recover quickly and the effect may be considered a form of paralysis (§28).

123. This is not surprising when the form is blindingly bright. A person who has looked at the sun may retain its afterimage for several days. Boyle tells of one case lasting ten years.

124. The same thing also occurs to some degree with forms that are not blindingly bright. Büsch relates that the image of an engraving complete in every detail persisted in his own eye for about seventeen minutes.

125. Several people inclined to attacks of spasm and plethora of blood retained the image of a bright red calico with a white shell pattern for many minutes, and saw it floating everywhere like a veil. It disappeared only after they had rubbed their eyes for a long time.

126. Scherffer notes the persistence over several hours of the purple *produced as a strong impression of light fades.*

127. We can create the appearance of light on the retina by applying pressure to the eyeball. With slight pressure a red color also appears and the experience of a fading light is produced.

128. Upon awakening, many sick people see everything tinged with the reddish color of dawn, as though through a red veil. This will also

happen frequently when they doze off and wake up again while reading in the evening. The effect remains for several minutes but can be made to disappear by rubbing the eyes a bit. It is sometimes accompanied by red stars and balls. This condition of seeing red may continue for a long while.

129. Aeronauts, particularly Zambeccari[43] and his colleagues, claim to have seen the moon as blood red at their greatest altitude. Since they had already risen above the terrestrial haze through which we observe this color in the moon and sun, we can assume that the phenomenon must be counted among the pathological colors. It may be that their senses were so affected by this unfamiliar condition that the body as a whole, and especially the retina, fell into a state of inertia and insensitivity. So it is not beyond the realm of possibility that the moon had the effect of a subdued light and thereby produced the impression of red. The sun, too, appeared blood red to the Hamburg aeronauts.

Might not those cases in which aeronauts have difficulty in hearing one another come as much from insensitivity of the nerves as from rarefaction of the air?

130. Those who are ill also frequently see objects as multicolored. Boyle tells of one lady who bruised an eye in a fall and afterward saw objects, particularly white ones, shimmering in an almost intolerably vivid way.

131. Physicians apply the term "chrupsia" to a typhoid condition of the eye in which patients insist that they see colors around the boundaries between light and dark forms. Apparently a change takes place in the vitreous humor which impairs its achromatic quality.

132. In cataracts a heavily clouded lens causes the patient to see a red gleam. In one such case treated with electricity the red gleam turned yellow by degrees, then white as the patient began to see objects again. From this it may be concluded that the cloudiness in the lens was gradually clearing. When we have learned more about physical colors we will have no difficulty in finding a reason for this.

133. At this point we might assume that a person with jaundice sees through a vitreous humor which is actually tinted yellow, but that would involve the section on chemical colors. Thus it is easy to understand that we cannot fully complete the chapter on pathological colors without first becoming familiar with the theory of color in its entirety. We will therefore let the present treatise suffice until we have had an opportunity to discuss the topics indicated above.

134. Lastly, however, a few special idiosyncrasies of the eye deserve mention.

There are artists who suffuse their paintings with a general tone, either warm or cold, instead of reproducing colors as they are in nature.

Similarly, some painters show a predilection for certain colors while others display a lack of feeling for harmony.

135. Finally, it is worth noting that primitive nations, uneducated people, and children have a strong preference for vivid colors; that animals are enraged by certain colors; and that cultivated people avoid vivid colors in their dress and surroundings, and attempt to eliminate these colors altogether from their presence.

Part Two
Physical Colors

136. We will use the term physical colors to designate colors that require for their production certain material media which are themselves colorless. Some of these may be transparent, some may be turbid and translucent, and some completely opaque. Such colors are created in our eye by these external agents or, where they have been created beforehand in the outer world, they are reflected into our eye. Whether or not we ascribe a kind of objective existence to them, they most often have a transient and fleeting character.

137. In the works of earlier researchers they are therefore called *colores apparentes, fluxi, fugitivi, phantastici, falsi,* or *variantes*. At the same time they have been called *speciosi* and *emphatici* because of their striking splendor. They are directly connected to physiological colors and seem only slightly more real. In the case of physiological colors the eye was the principal agent and these phenomena were produced only within ourselves, not in the outer world. Although physical colors are unquestionably evoked in the eye by colorless objects, they also permit us to use a colorless surface in place of our retina and observe the phenomena on it externally. Every experiment of this type, however, will lead us to the firm conviction that we are not discussing fixed colors but rather colors which are evolving and changing.

138. With these physical colors we will therefore find it possible to place objective and subjective phenomena side by side and, at times, to succeed in penetrating more deeply into the nature of the phenomenon by comparing the two.

139. Thus in experiments on physical colors we will neither regard the eye as acting alone nor consider light in direct relationship with the eye. Instead we will turn our attention to the question of how certain modifying factors are introduced through mediating agents, agents which are themselves colorless.

140. Under these conditions light may be modified in three ways. First, when its rays reflect from the surface of a medium, in which case we speak of *catoptric* experiments. Second, when its rays pass across

the edge of a medium. The phenomena appearing then were earlier called *perioptic*, but we will use the term *paroptic*. Third, when the light passes through a translucent or transparent body, which occurs in *dioptric* experiments. We have applied the term *epoptic* to a fourth type of physical color because it appears under various circumstances on the colorless surface of objects without any intervening process of mediation (βαφή).[44]

141. If we examine the above categories according to our major classification of color into its physiological, physical, and chemical aspects, we will find that the catoptric colors are closely related to the physiological, the paroptic diverge a bit and become somewhat independent, the dioptric show an entirely physical quality with a decidedly objective side, while the epoptic form a transition to chemical color, although only apparently so in their first stages.

142. To pursue our argument according to the dictates of nature we would have to follow the above order. In didactic discourse, however, connecting the topics under discussion is not as important as separating them clearly; the individual elements are assimilated into a greater unity only at the end, after every detail has been placed before the mind. So we will turn right away to dioptric colors to bring the reader immediately into the midst of physical color and acquaint him further with its properties.

IX. Dioptric Colors

143. The term dioptric is applied to those colors which require a colorless medium for their creation, with the stipulation that light and dark must pass through the medium and affect either the eye or a surface standing opposite. It is therefore necessary that the medium be transparent or at least translucent to some degree.

144. In accordance with these requirements we will divide dioptric phenomena into two classes. We will include phenomena produced by translucent turbid media in the first, while the second will include those which appear when the medium is transparent in the highest possible degree.

X. Dioptric Colors of the First Class

145. A space conceived of as empty would exhibit the property of transparency to an absolute degree. If this space is then filled by a substance imperceptible to the eye, a transparent medium will arise which is material in character and more or less dense. This medium may be aeriform or gaseous, liquid, or even solid.

146. Pure translucent turbidity is a property derived from transpar-

ency. Therefore it may also present itself to us in one of the three forms mentioned above.

147. Full turbidity is white. It is the brightest, most neutral form of space occupied by matter, and the first degree of opacity.

148. In empirical terms, transparency is the first degree of turbidity. The further stages of turbidity up to opaque white are infinite in number.

149. Brought into relation with light and darkness, any degree of turbidity short of opacity will yield phenomena which are simple and worthy of note.

150. The most energetic light is blinding and colorless (e.g., sunlight or phosphorus burning in oxygen). Similarly, the light of the fixed stars comes to us largely without color. When viewed through a medium which is the least bit turbid, however, this light will seem yellow. As the medium becomes more turbid or its thickness increases we will see the light gradually assume a yellow-red cast and ultimately intensify to ruby red.

151. On the other hand, darkness viewed through a turbid medium filled with light will create a blue color which grows lighter and paler as the medium becomes more turbid, but darker and deeper as it becomes more transparent. With the minimal degree of the most rarefied turbidity this color will appear to the eye as a beautiful violet.

152. The phenomenon described here occurs in the eye and may therefore be classed as subjective, but we can also find further corroboration for it in objective phenomena. A light subdued and beclouded in this fashion also casts a yellow, yellow-red, or purple illumination on objects, and although the effect of darkness is not expressed so forcefully through a turbid medium, a blue sky will clearly be present along with other colored objects on the white paper in a camera obscura.

153. We can begin our discussion of the circumstances under which this important and fundamental phenomenon appears by considering atmospheric colors, most of which belong in this category.

154. Viewed through a certain degree of haze the sun appears as a yellowish disk. Often the center remains a blinding yellow even after the edge has turned red. The sun appears ruby red when a layer of fine dust is in the upper atmosphere (an event visible in northern Europe in 1794). When the atmospheric conditions peculiar to the sirocco prevail in southern regions the sun together with the clouds often surrounding it will seem an even deeper ruby red; these clouds will also radiate the color by reflection.

The red color at sunrise and sunset is produced in the same way. The sun is heralded by a red color because its rays come to us through a thicker layer of haze. The higher it climbs in the sky, the lighter and yellower its light becomes.

155. The darkness of infinite space viewed through atmospheric par-

ticles illuminated by sunlight will produce blue. On high mountains the heavens are seen by day as royal blue because only a few thin layers of haze float before the dark infinity of space. When we descend to the valleys this blue will become lighter until in certain regions, and with increasing haze, it finally changes completely to a whitish blue.

156. Mountains seem blue to us for the same reason: when so distant that the colors of their features are no longer visible and the light reflected from their surfaces no longer affects our eye, they will act as completely dark objects and look blue through the intervening haze.

157. When there is a fine haze in the air we also have the impression that the shadowed parts of nearby objects are blue.

158. Distant icebergs, however, still seem white with a tendency toward yellow. This is because even through the atmospheric haze they retain their effect of brightness on the eye.

159. The appearance of blue in the lower part of a candle flame also belongs in this category. If we hold the flame against a white background we will find no trace of blue, but this color will appear immediately when we hold the flame against a dark background. This phenomenon is most vivid when we light a spoonful of alcohol.[45] Thus we may consider the lower part of the flame a haze; although extremely fine, this haze will become visible against the dark surface. It is so fine that we are able to read through it without difficulty. Conversely, the tip of the flame, through which no object can be seen, must be considered a body producing its own light.

160. Lastly, smoke must also be considered a turbid medium: it seems yellow or red against a light background, but blue against a dark one.

161. Turning now to the fluid media, we find that water of any sort will produce the same effect when made slightly turbid.

162. The infusion of nephritic wood (*guilandina Linnaei*), an object of so much attention in the past, is merely a turbid liquid. It would necessarily look blue in a dark wooden cup but produce a yellow appearance when held to the sun in a transparent glass.

163. A few drops of perfume, spirit varnish, or certain metallic solutions are enough to create any degree of turbidity in the water to be used for such experiments. Tincture of soap is perhaps the most effective.

164. In bright sunlight divers see the ocean bottom as purple; here the water acts as a thick turbid medium. Under these circumstances they see shadows in green, the complementary color (§78).

165. The opal is foremost among solid media found in nature. At least in part, its colors may be attributed to the fact that it is really a turbid medium through which a mixture of light and dark substrata are visible.

166. The most satisfactory material for any of these experiments,

however, is opal glass (*vitrum astroides, girasole*). It is manufactured by various methods and its turbidity is produced by metal oxides. Powdered and calcined bones may also be melted together with the glass to create turbidity and yield what is often called bone glass, but glass made by this method turns opaque far too quickly.

167. Glass for these experiments can be prepared in several ways. We may make it only slightly turbid, in which case we can progressively transform light from the palest yellow to the deepest purple by adding layers of glass. We may also use very turbid glass in sheets of varying thicknesses. Our experiments can be done by either method, but to see the deep blue color we must be especially careful to avoid glass which is too turbid or thick. Since darkness naturally produces a weak effect through turbidity, the medium will quickly turn white when too dense.

168. Clouded spots in window glass will cast a yellow light on objects; the same places in the glass look blue when we view a dark object through them.

169. Smoked glass also deserves mention here and must likewise be considered a turbid medium. It causes the sun to appear more or less ruby red, and although at first we might think that this color results from the brownish black of the soot, we can show that it is the consequence of a turbid medium by looking at a dark object through a lightly smoked glass illuminated frontally by the sun; we will then observe a bluish cast.

170. A striking experiment may be performed with sheets of parchment in a dark room. A single sheet of parchment over the aperture of a window shutter in the sunlight will seem whitish. Adding a second piece will produce a yellow color which will intensify and finally turn to red as we add further pieces of parchment.

171. We have already observed such an effect brought about in cataracts by a clouded lens (§132).

172. Although our discussion has now led us to the effect of a turbidity which allows very little light to pass, one strange case of temporary turbidity still deserves mention.

Some years ago the portrait of an eminent theologian was painted by an artist who was especially good at the practical use of color. His Reverence stood there in a glistening velvet coat which attracted as much attention as the man's face and aroused great admiration. With the deposit of soot and dust the picture had gradually lost much of its original brilliance. It was therefore sent to an artist for cleaning and a new coat of varnish. The artist began to wipe the dirt carefully from the picture with a damp sponge. He had scarcely removed the worst of the dirt with a few strokes of the sponge when to his astonishment the black velvet of the coat suddenly changed to a light blue plush, giving the cleric a quite worldly if somewhat old-fashioned appearance.

The painter was too perplexed to continue with the cleaning; he could not understand how a light blue might serve as the ground for such a deep black, and still less how he could so easily have rubbed off a glaze heavy enough to transform the blue he now saw before him into black.

In short, he was aghast at having ruined the picture to this extent. Nothing of a religious nature remained apart from the richly curled, rounded wig, a feature which made the exchange of a fine new black velvet coat for one of faded plush altogether unsuitable. The damage seemed irreparable at the moment. Our good painter dejectedly turned the picture to the wall and retired full of care to his bed.

You may imagine his relief the following morning when he took up the picture once more and saw the black velvet coat restored to its full splendor. He could not resist the temptation to dampen one edge of the coat again, at which point the blue reappeared and then disappeared after a time.

When I heard of this phenomenon I immediately went to see the picture. While I was there a damp sponge was wiped across the picture and the transformation appeared in an instant. I saw a plush coat which was entirely pale blue, although somewhat faded; a few brown strokes on the arm of the coat indicated the folds.

My explanation for this is based on the theory of turbid media. The artist had probably applied a special varnish over an underlayer of black to give it depth. This varnish absorbed some moisture as it was washed, thereby becoming turbid and making the underlying black promptly appear as blue. Someone familiar with varnishes may discover by accident or deduction how to present this phenomenon experimentally to those interested in scientific research. Despite many attempts I have been unable to do so.

173. Our primary experiment with turbid media has helped us find an explanation for the most sublime atmospheric phenomena as well as effects more obscure but no less meaningful. These phenomena take many different forms in the world, and we are confident that observant friends of nature will continue to school themselves in the application of this approach to understanding and explaining them.

174. The principal phenomenon outlined in the above discussion might be called a fundamental or archetypal phenomenon. With the reader's permission we will proceed at once to clarify what is meant by this.

175. In general, events we become aware of through experience are simply those we can categorize empirically after some observation. These empirical categories may be further subsumed under scientific categories leading to even higher levels. In the process we become familiar with certain requisite conditions for what is manifesting itself. From this point everything gradually falls into place under higher principles and laws revealed not to our reason through words and hypoth-

eses, but to our intuitive perception through phenomena. We call these phenomena *archetypal phenomena* because nothing higher manifests itself in the world; such phenomena, on the other hand, make it possible for us to descend, just as we ascended, by going step by step from the archetypal phenomena to the most mundane occurrence in our daily experience. What we have been describing is an archetypal phenomenon of this kind. On the one hand we see light or a bright object, on the other, darkness or a dark object. Between them we place turbidity and through this mediation colors arise from the opposites; these colors, too, are opposites, although in their reciprocal relationship they lead directly back to a common unity.

176. In this sense we consider the error which has sprung up in scientific research on color to be a grievous one.[46] A secondary phenomenon has been placed in a superior position and an archetypal phenomenon in an inferior one; moreover, the secondary phenomenon itself has been turned upside down by treating what is compound as simple and what is simple as compound. In this manner the most bizarre complications and confusions have come topsy-turvy into natural science, and science continues to suffer from them.

177. But even where we find such an archetypal phenomenon, a further problem arises when we refuse to recognize it as such, when we seek something more behind it and above it despite the fact that this is where we ought to acknowledge the limit of our perception. It is proper for the natural scientist to leave the archetypal phenomenon undisturbed in its eternal repose and grandeur, and for the philosopher to accept it into his realm. There he will discover that a material worthy of further thought and work has been given him, not in individual cases, general categories, opinions and hypotheses, but in the basic and archetypal phenomenon.

XI. DIOPTRIC COLORS OF THE SECOND CLASS (REFRACTION)

178. After some observation we will soon find that the two classes of dioptric colors are closely related. Those of the first class appeared in the presence of turbid media; those of the second will now appear before us in transparent media. The close relationship between the two classes becomes evident when we consider that all transparent objects found in the empirical world may be viewed from the outset as turbid by nature, a fact demonstrated when we increase the mass of the medium we call transparent.

179. In dealing with transparent media, however, we will for now overlook the fact that they are inherently turbid to a degree, and concentrate our full attention on the phenomenon that arises here, a phenomenon known technically as refraction.

180. In our discussion of physiological colors we vindicated certain so-called optical illusions by showing them to be the activity of a healthy eye which is functioning properly (§2). Here we will again have an opportunity to say something on behalf of our senses which reaffirms their reliability.

181. Throughout the sensory world the relationship of one thing to another is of paramount importance, especially the relationship of the most significant thing on earth, man, to all the rest. Thus the world is divided into two parts and man as subject confronts the object. Here the practical person exhausts himself in experimentation, the thinker in speculation; they are required to enter a conflict never to be resolved peacefully nor concluded decisively.

182. But even here an accurate grasp of relationships is fundamental, and since our senses (insofar as they are healthy) most truly indicate outer relationships, we may conclude that wherever they appear to contradict reality they disclose the true situation all the more surely. Thus distant objects seem smaller to us, and through this very fact we become aware of their distance. Using colorless objects and colorless media we produced the phenomena of color, and thereby noted the degree of turbidity in such media.

183. Similarly, refraction reveals to our eye the varying degrees of thickness in transparent media, as well as other physical and chemical characteristics peculiar to them. This fact will lead us to undertake further tests to find the physical and chemical means of penetrating into these secrets fully, although from one standpoint they have already been laid open.

184. Objects seen through a medium having some degree of thickness do not appear where we would expect them to be according to the laws of perspective. Dioptric phenomena of the second class depend on this fact.

185. The laws of sight subject to mathematical formulation are based on the following: light travels in a straight line, and thus it should be possible to draw a straight line between the organ of sight and the object seen. Therefore if we find light following a curved or broken line, if we see objects along a curved or broken line, we immediately recognize that the intervening medium has thickened, that it has somehow taken on a different character.

186. This deviation from the law of straight-line vision is generally called refraction. Although we assume that the reader is already familiar with refraction, we will describe it here briefly in its objective and subjective aspects.

187. We will let the sun shine diagonally into an empty cubical container so that the light falls only on the side opposite the sun, not on the bottom. If we then fill the container with water, the position of the light will immediately change relative to the container. The light will

draw back toward the side from which it came and illuminate part of the bottom. Where the light enters the thicker medium it will deviate from its straight path and appear broken—hence the term "breaking" or "refraction." Enough said of our objective experiment.

188. We may arrive at our subjective experiment as follows: let us locate our eye where the sun was, our line of sight also a diagonal over one side of the container so that the eye sees the entire inner surface of the side opposite, but not the bottom. When we pour water into the container the eye will also glimpse part of the bottom; this actually occurs in a way which leads us to believe we are still looking along a straight line, for the bottom appears to have been raised. This is why we will use the term "elevation" for this subjective phenomenon. Later we will discuss several other points of special interest in this regard.

189. To put this phenomenon into general terms we may repeat what was indicated above: the relationship of objects is altered or displaced.

190. In our present description, however, we intend to distinguish between objective and subjective effects, and so we will begin by describing the phenomenon subjectively with the statement that there has been a displacement of what we saw or were to see.

191. Something seen without boundaries may be displaced without our noting the effect. However when something seen as bounded is displaced we will have evidence of the displacement. Therefore if we wish to learn more about such a change in relationship we must limit ourselves largely to the displacement of what is bounded, the displacement of forms.

192. This effect as a whole may occur in media with parallel sides, since every such medium displaces the object by bringing it toward the eye along a perpendicular. However the displacement is more noticeable in media with nonparallel sides.

193. These can be completely spherical in shape or find application as convex or concave lenses; in our experiments we will also call upon such media. However, since they not only displace a form but also alter it in many ways, we prefer to use a medium with surfaces which are nonparallel yet flat; i.e., the prism, based on the triangle. We may think of it as part of a lens, but the prism is especially useful here because it produces a strong displacement of the form without any significant distortion in shape.

194. To conduct our experiments with the greatest possible precision and avoid confusion, we will at first limit ourselves to

subjective experiments;

i.e., those in which the observer sees the object through a refractive medium. After we have dealt with these systematically, our objective experiments will follow in the same order.

XII. REFRACTION WITHOUT THE APPEARANCE OF COLOR

195. Refraction may occur without producing any appearance of color. Anything unbounded, a colorless or uniformly colored surface, will produce no color regardless of the degree to which refraction displaces it. This may be demonstrated in several ways.

196. If we place a glass cube on a homogeneous surface and view it perpendicularly or from an angle, the entire surface will be lifted toward the eye without any color appearing. When we look through a prism at a homogeneously gray or blue sky, or at a wall which is uniformly white or colored, the part of the surface we see will be displaced as a whole, but we will find no hint of color in it.

XIII. CONDITIONS FOR THE APPEARANCE OF COLOR

197. In the above experiments and observations we found all homogeneous surfaces, large or small, to be without color. But color will appear at those boundaries where such a surface contrasts with a lighter or darker object.

198. Forms are created through a combination of boundary and surface. We will therefore state our basic observation as follows: a form must be displaced if colors are to appear.

199. Let us consider the simplest form, a light disk on a dark background (Plate II, fig. A; see plates following page 206). A displacement will occur in this form when we seemingly expand its borders away from the center by magnifying it. Any convex glass will accomplish this, and in this case we will observe a blue border (fig. B).

200. We can seemingly move the circumference of the same form inward toward the center by reducing the disk; in this case the borders will appear yellow (fig. C). A concave glass will do this, but the glass must be fairly thick, not ground thin as in ordinary eyeglasses. To observe this in a single experiment with the convex glass we may place a smaller black disk in the center of the light form lying on the black background. Magnification of a black disk on a white background has the same effect as reduction of the white disk: we move the black border toward the white one and therefore see the yellowish border color and the blue border color at the same time (fig. D).

201. These two colors, blue and yellow, appear across the white surface and at its edge. Where they extend across the black surface they take on a reddish appearance.

202. We have presented above the basic phenomena found in every appearance of color produced by refraction. These may, of course, be repeated, varied, enhanced, diminished, combined, complicated or confused in many ways, but in the end it is always possible to reduce them to their original, simple form.

203. Let us now consider what we have done. In the first case we seemingly moved the light border toward the dark surface, while in the second we moved the dark border toward the light surface; we replaced one with the other, thrust one across the other. We will now proceed step by step with the rest of our experiments.

204. When we displace the light disk as whole—prisms are particularly suited for use here—the disk will take on color in the direction of the apparent shift in accordance with the principles mentioned above. If we observe a disk in position *a* (Plate II) through a prism so that it appears to be displaced in direction *b*, the outer edge will appear blue and blue-red (in accordance with the principle in figure B) while the inner edge will appear yellow and yellow-red (in accordance with the principle in figure C). This occurs because the light form appears to be shifted across the dark boundary in the first instance, while in the second the dark boundary is shifted across the light form. The same thing occurs when we seemingly shift the disk from *a* toward *c*, from *a* toward *d*, and so on through a full circle.

205. Compound phenomena behave in the same manner as simple ones. If we look through horizontal prism *ab* at white disk *e* (Plate II) located some distance from the prism, the disk will be shifted in direction *f* and colored in accordance with the above principles. If we remove the horizontal prism and use vertical prism *cd* to view the form, it will appear at *h* with its colors conforming to the same principles. If we then place the two prisms across one another, the disk will appear to be displaced diagonally as required by natural law, and display the color produced by direction *eg*.

206. When we look closely at the colored borders lying opposite one another on the disk we will discover that they appear only in the direction of its apparent movement. Although a round form leaves us somewhat unclear about this relationship, a square form will provide unmistakable evidence of it.

207. Square form *a* (Plate II) displaced in direction *ab* or *ad* will display no color on the sides parallel to the direction of displacement. However, if the form is displaced in direction *ac* all four of its sides will appear colored, for it has moved diagonally.

208. Here we find confirmation for the assertion (§203 ff.) that the form must be displaced so that a light boundary appears to be shifted across a dark surface while a dark boundary is shifted across a light surface; the form appears to be shifted across the surface adjacent to it and the adjacent surface across the form. However, when the straight boundaries of a form are extended by refraction so that they run side by side without overlapping, no color appears; no color would appear even if the boundaries were extended to infinity.

XIV. CONDITIONS UNDER WHICH THE APPEARANCE OF COLOR INCREASES

209. We have seen above that the appearance of color in refraction is a result of displacing the boundary of a form across the form itself or across its background, of shifting the form, as it were, over itself or its background. In addition, with more pronounced displacement the appearance of color will increase. In subjective experiments (still the subject of our discussion) this occurs under the following conditions:

210. First, when the eye's line of sight to a medium with parallel sides becomes more oblique.

Second, when the sides of the medium are no longer parallel and form an angle which is to some degree acute.

Third, through an increase in the mass of the medium: media with parallel sides may be enlarged in volume or the acute angle may be increased, provided it does not become a right angle.

Fourth, when the eye together with its medium of refraction are moved further from the form to be displaced.

Fifth, through a chemical property either added to the glass or intensified in it.

211. The maximum displacement of a form without appreciable distortion in shape is produced by using a prism, and thus the appearance of color may become quite powerful through a piece of glass fashioned in this way. However, in working with prisms we must try not to let these shining phenomena bedazzle us, but seek instead to keep the simple fundamentals established above firmly in mind.

212. The color which takes the lead when a form is displaced is always the broader one, and we will use the term "fringe" for it; the color remaining at the boundary is the narrower one, and we will use the term "border" for it.

213. When we shift a dark boundary across a light surface, a broad yellow fringe leads the way and a narrower yellow-red border follows at the boundary. When we displace a light boundary across a dark surface, a broad violet fringe takes the lead and a narrower blue border follows.

214. In a large form the central portion will remain without color; this center must be considered an unbounded surface which is displaced without being altered. But the center will be completely covered by color when the form is so narrow that (under the four conditions mentioned above) the yellow fringe can reach across to the blue border. For this experiment we can use a white stripe against a black background; the two extremes will easily merge across the white stripe and produce green. We will then see the following sequence of colors:

Yellow-red
Yellow
Green
Blue
Blue-red

215. If we place a black stripe on a white piece of paper, the violet fringe will extend across it to the yellow-red border. Here the black area in the middle will be eliminated, as was the white previously, and in its place a magnificent pure red will appear, a color we have frequently designated as purple. Now the sequence of colors will be as follows:

Blue
Blue-red
Purple
Yellow-red
Yellow

216. The yellow and blue in the first instance (§214) may reach across one another far enough to merge the two colors as green, and the colored form will appear as follows:

Yellow-red
Green
Blue-red

Under similar circumstances in the second instance (§215) we will see only:

Blue
Purple
Yellow

This latter phenomenon appears beautifully when we look at bars of a window against a gray sky.

217. In all that we have observed we should always remember that this phenomenon must not be thought of as fixed or complete, but rather as evolving, growing, and open in many ways to modification. This is why a reversal of the five conditions listed above (§210) will lead to a gradual decrease in the phenomenon and ultimately to its complete disappearance.

XV. SOURCE OF THE FOREGOING PHENOMENA

218. Before continuing we will make use of the above to find a source or, if you prefer, an explanation for the fairly simple phenomena pre-

sented at the beginning of our investigation. This may give the friend of nature a clear insight into the more complex phenomena to follow.

219. Above all, we must remember that we are in the realm of forms. In general, our sense of sight is most attracted to what is seen as bounded. In our present discussion concerning the appearance of colors caused by refraction, we will consider nothing but what is seen as bounded, nothing but the form.

220. However, for the purposes of our chromatic observations we may divide forms in general into *primary* and *secondary* forms. The terms themselves indicate what is meant; the following will further clarify our meaning.

221. First, we may consider primary forms as *original* forms engendered in our eye by the object before us; such forms attest to the object's real existence. In contrast, we may consider secondary forms as *derived* forms which remain in the eye when the object is removed, the afterimages and counterimages discussed at length in the section on physiological colors.

222. Secondly, we may also consider primary forms as *direct* forms which, like original forms, come from the object to our eye without mediation. In contrast, we may consider secondary forms as *indirect* forms merely passed on to us secondhand by a reflecting surface. The latter are catoptric images which may also become double images in certain cases.

223. In other words, when the reflecting body is transparent and has two parallel surfaces lying one behind the other, an image from each surface may strike the eye. Double images will then be formed insofar as the upper image does not entirely cover the lower one. This can occur in various ways.

Let us hold a playing card up to a mirror. We will immediately observe the appearance of the card's sharp, vivid image, but the border of the whole card and of each discrete form on it will be edged with a fringe which forms the beginning of a second image. The effect will vary from mirror to mirror, depending on differences in the thickness of the glass and random inconsistencies in polishing. This fringe shows up strongly in many mirrors when we stand in front of them wearing a white vest over dark clothing; here we may also clearly observe the double image of metal buttons on dark cloth.

224. Those familiar with the experiments described earlier (§80) will more easily follow the present discussion. Window bars reflected in a pane of glass will appear double, and their images may be separated entirely where the glass is thicker and the angle of reflection greater. Similarly, a container of water with a flat reflective bottom will show objects held before it as double and separated to a degree dictated by the circumstances. Here we will note that where the two images coincide

a perfectly sharp image is actually created, but where this image separates and becomes double, forms appear which are weak, translucent, and ghostly.

225. We may use tinted media if we wish to discover which image is on the bottom and which on top, for a white form reflected from the bottom surface will have the color of the medium while its reflection from the top surface will have the complementary color. The reverse is true of dark forms; thus black and white squares are also useful here. This will provide another striking demonstration of how easily double images take on color or call it forth.

226. Thirdly, we may also consider primary forms as *principal* forms and, in effect, append secondary forms to them as *auxiliary* forms. Such an auxiliary form is a type of double image; however it cannot be divorced from the principal form although it constantly shows a tendency to become separate. It is these forms which will concern us when we come to prismatic phenomena.

227. An unbounded surface viewed by refraction produces no color (§195). The object viewed must be bounded, and therefore a form is required. The form is displaced by refraction, but not completely, not absolutely, not sharply; it is displaced incompletely so that an auxiliary form is created.

228. We must not come to a standstill when confronted by individual phenomena in nature, especially those which are significant or striking; we must not dwell on them, cling to them, or view them as existing in isolation. Instead, we should look about in the whole of nature to find where there is something similar, something related. For only when related elements are drawn together will a whole gradually emerge which speaks for itself and requires no further explanation.

229. Hence it is appropriate to recall here that in certain cases refraction undeniably produces double images; e.g., in the case of what is called Iceland spar. Similar double images are also produced by refraction through large quartz crystals and in other ways—phenomena which have yet to receive the attention they deserve.

230. However, since the case under consideration (§227) involves auxiliary forms rather than double ones, we will return to a phenomenon mentioned earlier but not yet fully explored. We may call to mind our earlier observation (§16) that even with regard to the retina there is conflict of sorts in a light form on a dark background or a dark form on a light background. In this instance the light form seems larger and the dark one smaller.

231. On closer examination we will note that the forms are not sharply delineated against their backgrounds, but seem to exhibit a kind of gray, slightly colored border, an auxiliary form. If forms can produce these effects on the naked eye alone, what might they not do when a thick

medium intervenes? The things we consider alive in the highest sense of the word are not the only ones to create effects and endure them; indeed, all things with any degree of interrelationship produce effects on one another, and often quite profound ones.

232. Thus when refraction affects a form, an auxiliary form is created close to the principal one. The true form seems to lag somewhat behind as if resisting the displacement, but an auxiliary form goes on ahead for a distance as described above (§§212-216), and in a direction determined by the movement of the refracted form across itself and its background.

233. We have also noted (§224) that double images appear as forms split in two, transparent phantoms of a sort, much in the way that double shadows always appear as half-shadows. The latter take on color easily and produce it readily (§69); the former do so as well (§80). This is also true of an auxiliary form: instead of separating from the principal form it projects from it as a form split in two—thus the rapidity, ease, and energy with which it takes on color.

234. There is more than one way to show that prismatic color is an auxiliary form. It appears in the exact shape of the principal form. Whether the principal form is straight or curved, serrated or undulating, the auxiliary form will always have the exact contours of the principal form.

235. The auxiliary form will share not only the shape of the actual form, but other features as well. Where the principal form contrasts sharply with the background (e.g., white on black), the colored auxiliary form will also appear quite forcefully; it will be vivid, clear, and powerful. It is most powerful, however, where a luminous form appears against a dark background. There are several ways to produce this effect.

236. But where the contrast between the principal form and its background is weak (e.g., gray forms on black and white, or even on one another), the auxiliary form will also be weak; it may become almost indiscernible where the difference in tone is small.

237. We can also observe remarkable effects with colored forms on a light, dark, or colored background. Here the color of the auxiliary form merges with the actual color of the principal form. The result is a compound color either enhanced by harmony or degraded by ugliness.

238. In general, however, semitransparency is a distinguishing feature of double and auxiliary forms. Thus if we suppose that within a transparent medium—with its tendency to become only semitransparent or translucent (noted above, §147)—if we suppose that within this medium there is a semitransparent phantom form, we will immediately recognize it as a turbid form.

239. Thus it is a simple matter to find the source for refractive color

in the principles of turbid media. For where the forward fringe of the turbid form shifts away from a dark area and across a bright one, yellow appears; alternately, where a light boundary extends across the adjacent dark area, blue appears (§§150, 151).

240. The forward color is always the broader one. Thus the yellow extends across light in a broad fringe, but at the boundary of the dark area a narrower yellow-red edge is formed in accord with the principles of intensification and darkening.

241. On the opposite side the compressed blue remains at the boundary while the forward fringe spreads over the black as a thin veil of turbidity, thus giving us violet. This conforms to the principles indicated earlier in the section on turbid media; later we will find the effect of these principles equally evident in several other cases.

242. Since an explanation such as this must actually prove itself under the eyes of the researcher, we would ask of each reader that he study the above description with full attention, not just in passing. Here we have not sought to replace the phenomena with arbitrary symbols, letters, or whatever might suit our pleasure; here we have not passed on clichés to be repeated endlessly without thinking or giving cause for thought. We speak, instead, of phenomena which must be present before our physical eyes, and those of the mind, if we are to provide ourselves and others with a clear explanation of how they arise.

XVI. DECREASE IN THE APPEARANCE OF COLOR

243. To understand or produce a decrease in the appearance of color we need only reverse the progression of the five conditions (§210) leading to its increase. We will provide just a brief description and review of what the eye sees as this takes place.

244. When the opposite edges overlap fully, the colors will appear as follows (§216):

Yellow-red	Blue
Green	Purple
Blue-red	Yellow

245. With less overlap the phenomenon appears as follows (§§214, 215):

Yellow-red	Blue
Yellow	Blue-red
Green	Purple
Blue	Yellow-red
Blue-red	Yellow

Here the forms still appear wholly in color, but these sequences should not be thought of as primary ones developing out of one another

like a series of steps or scales. We can and must separate them into their elements if we wish to learn more about their nature and character.

246. *These elements are (§§199, 200, 201):*

Yellow-red	Blue
Yellow	Blue-red
White	Black
Blue	Yellow-red
Blue-red	Yellow

Until now the principal form has been covered over and seemingly lost. Here it reemerges in the middle of the image and asserts its presence. Thus we recognize clearly the secondary nature of the auxiliary *forms appearing as borders and fringes.*

247. We may make these borders and fringes as narrow as we wish and even reduce refraction to the point where no color appears at the boundary.

This color phenomenon has now been sufficiently described. We will not declare it a primary phenomenon,[47] for we have traced it to a simpler, more basic one: in conjunction with the principle of secondary forms, it originates in the archetypal phenomenon of light and dark seen through a turbid medium. Thus prepared we will describe in detail the effects produced by gray or colored forms when displaced by refraction, *and so bring the section on subjective phenomena to a close.*

XVII. Gray Forms Displaced by Refraction

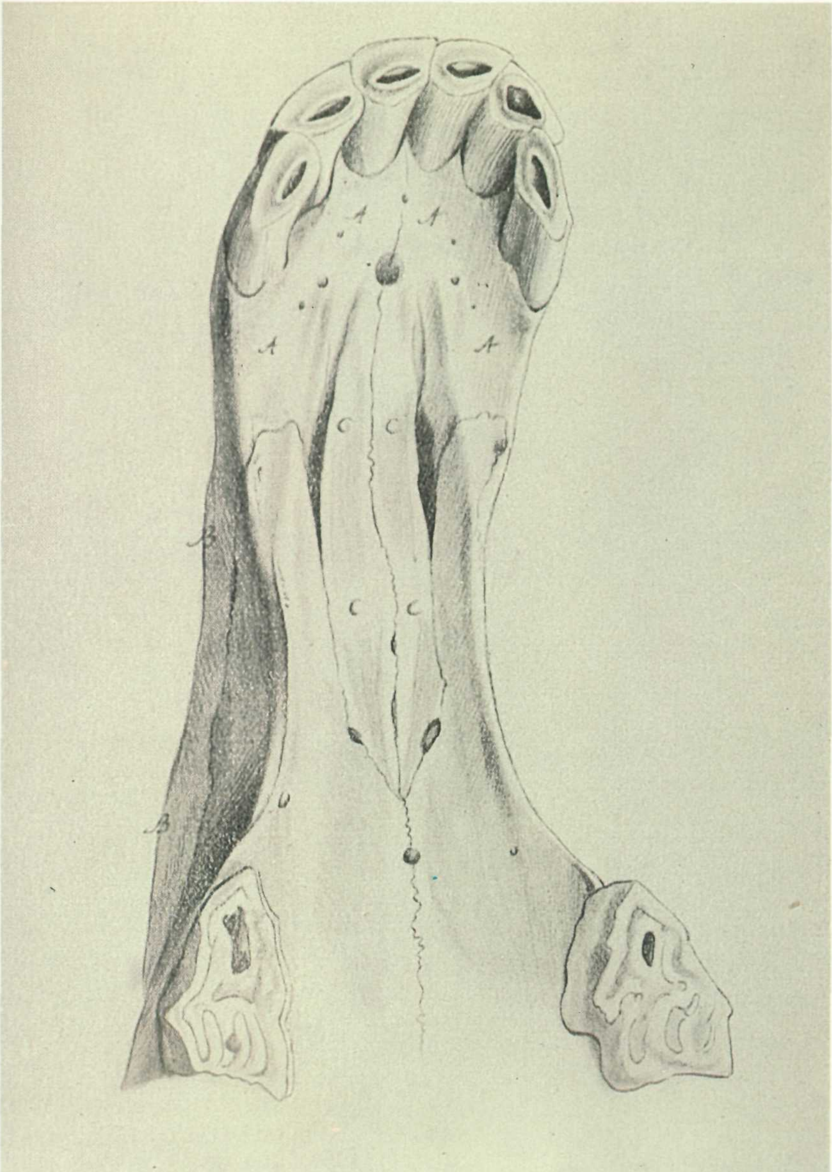
248. Thus far we have looked through the prism only at black and white forms on a contrasting background; this is because colored borders and fringes appear most clearly in such forms. We will now repeat these experiments with gray forms and find the results to be similar.

249. We have called black the representative of darkness and white the representative of light (§18); we can also say that gray represents *a semidarkness partaking in some degree of both light and darkness,* and thus situated between the two (§36). For the present discussion we recall the following phenomena.

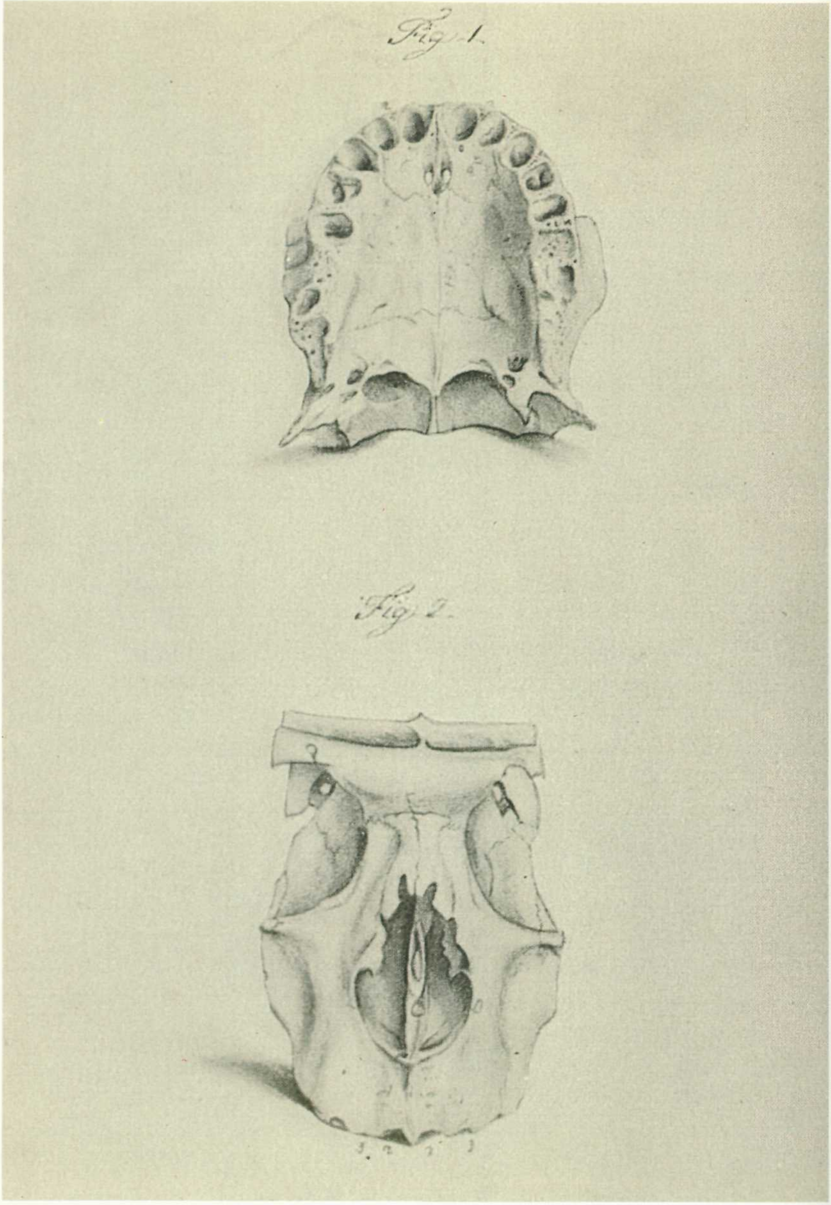
250. A gray form seems lighter on a black background than on a white one (§33), and will appear larger when seen as a light form on black, smaller when seen as a dark form on white (§16).

251. The darker the gray, the fainter its form on black and the stronger its form on white, and vice versa. Therefore dark gray yields only weak auxiliary forms on black and strong ones on white; light gray yields weak auxiliary forms on white and strong ones on black.

252. *Through a prism, gray on black will present the same phenomena* found with white on black: the borders will be colored in the same way,



Skull of a Horse (from *An Intermaxillary Bone Is Present in the Upper Jaw of Man As Well As in Animals*, Plate I). A: *Corpus;* B: *Apophysis maxillaris;* C: *Apophysis palatina.*



Human Skull (from *An Intermaxillary Bone Is Present in the Upper Jaw of Man As Well As in Animals,* Plate IX). 1: *Os intermaxillare* (bottom view); 2: *Os intermaxillare* (top view).

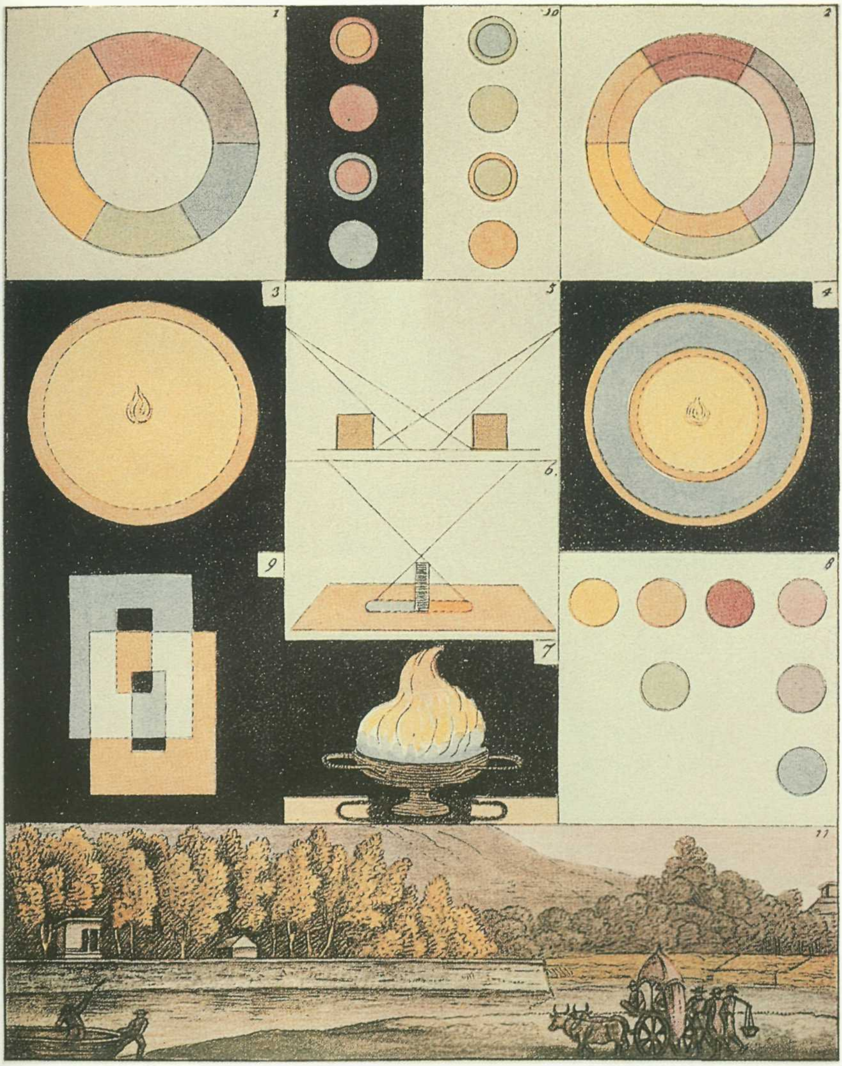


Plate I from *Theory of Color*. 1: color wheel; 2: color wheel (inset shows effects of acyanoblepsia); 3: objective halo on a candle-lit wall; 4: subjective halo seen around a candle flame; 5: method for observing colored shadows; 6: alternate method for observing colored shadows (shadows at sunrise or sunset); 7: flame against a black background; 8: test for acyanoblepsia; 9: double image in blue liquid against a reflective background; 10: fading of a blindingly bright colorless form; 11: landscape without blue as seen by an acyanoblepsic.

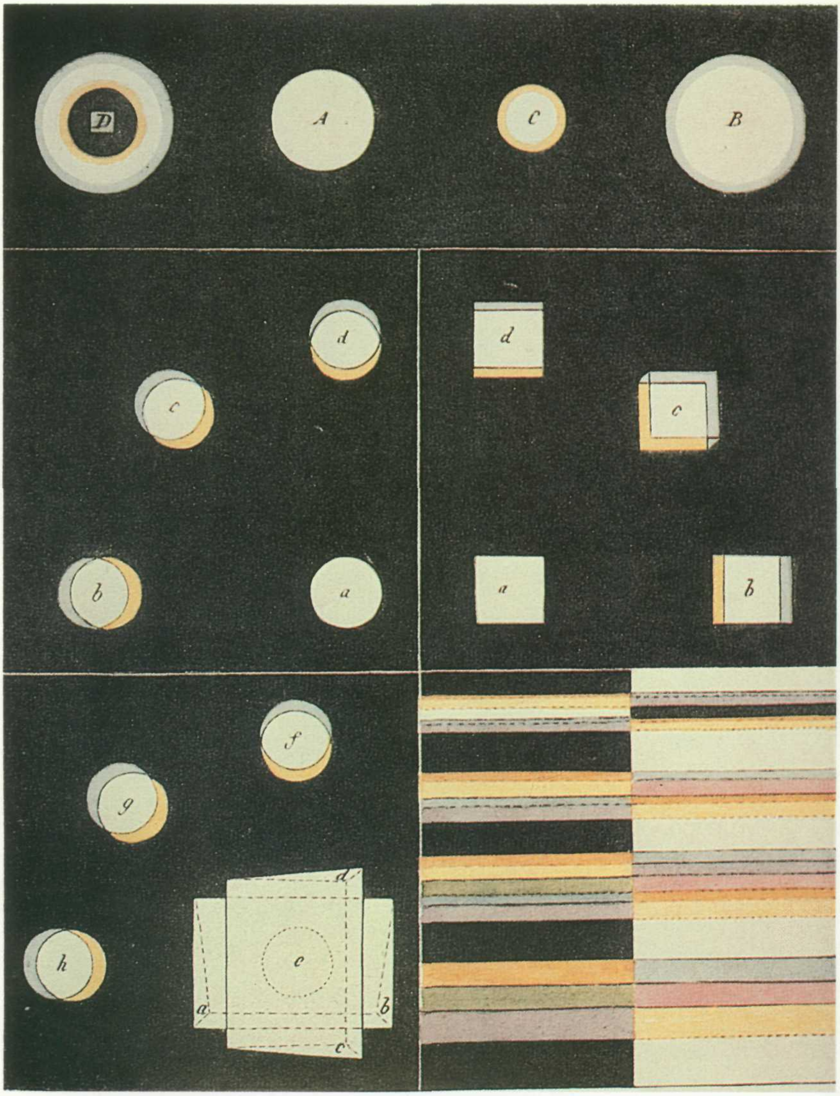


Plate II from *Theory of Color*. *(Top)* A: light disk on a black background; B: disk A through a convex lens; C: disc A through a concave lens; D: light disk with a small dark disk in the center as seen through a convex lens. *(Center Left)* Round forms through a prism. *(Center Right)* Square forms through a prism. *(Bottom Left)* Effect of combining two prisms. *(Bottom Right)* White and black stripes through a prism (increasing overlap of color).

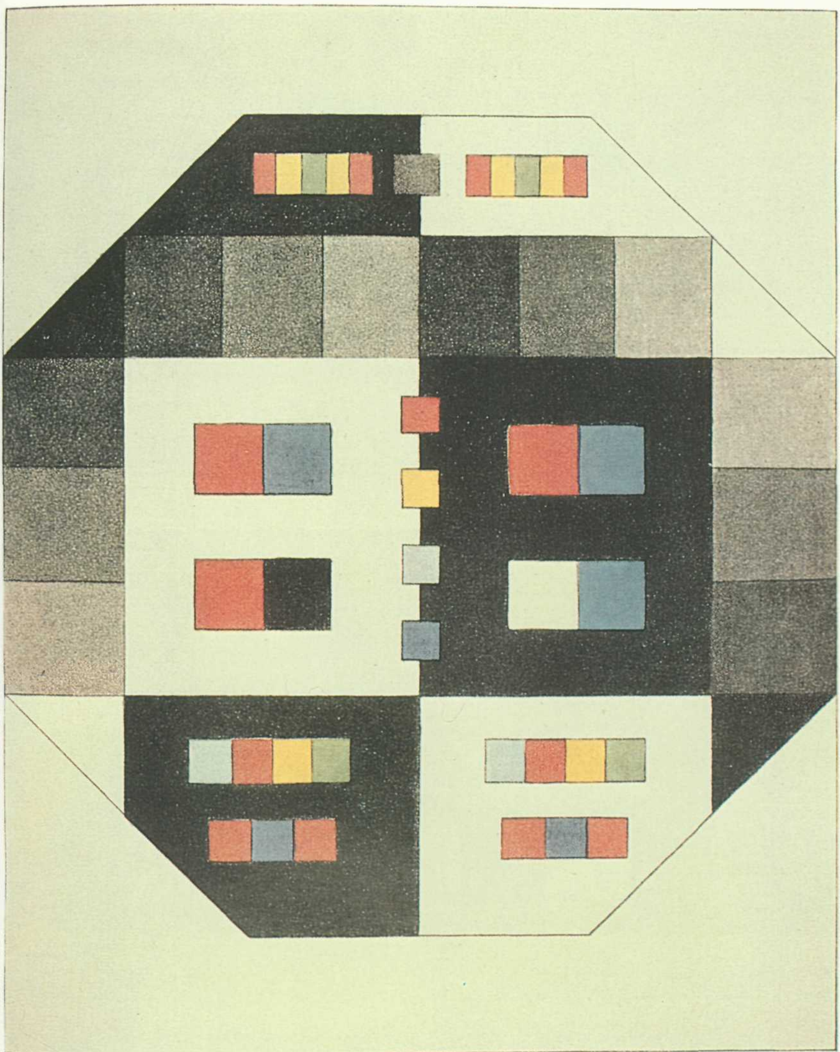


Plate III from *Theory of Color*. Colored forms to be viewed through a prism.

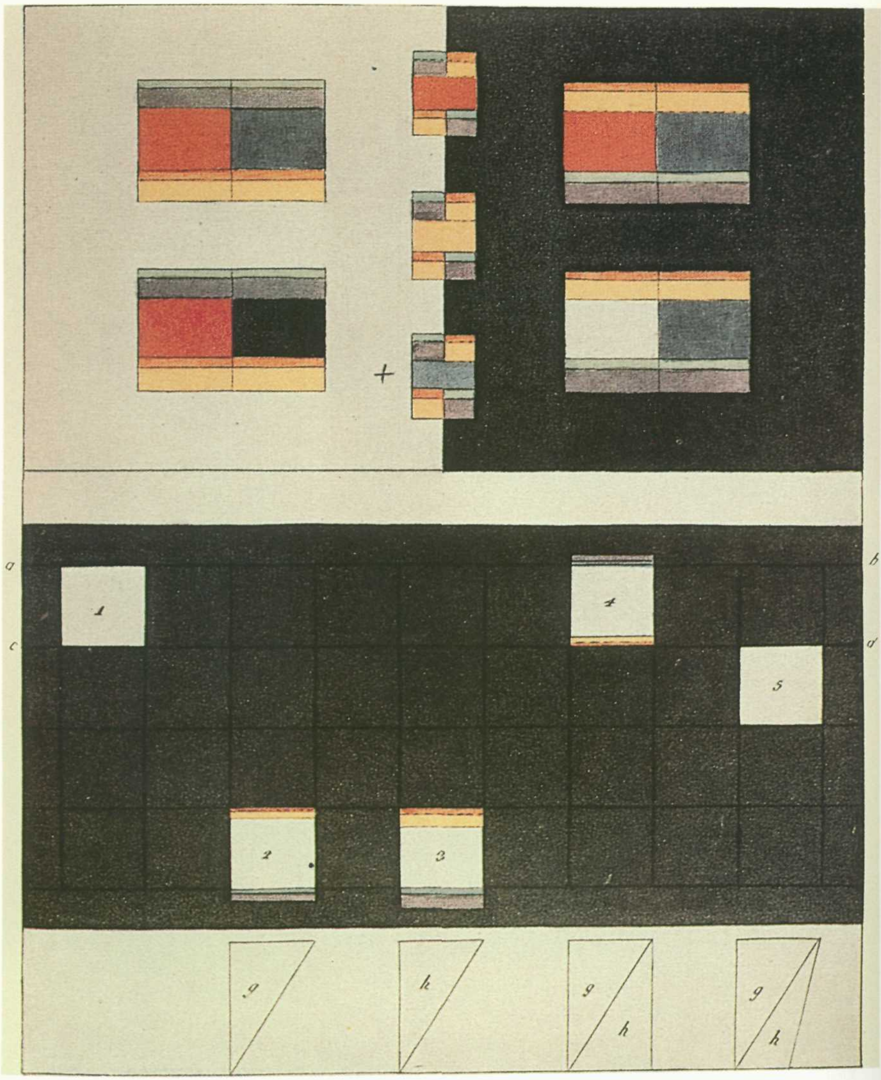


Plate IV from *Theory of Color*. *(Top)* Center section of Plate III as seen through a prism. *(Bottom)* Achromatic effects of crown glass (g) and flint glass (h).

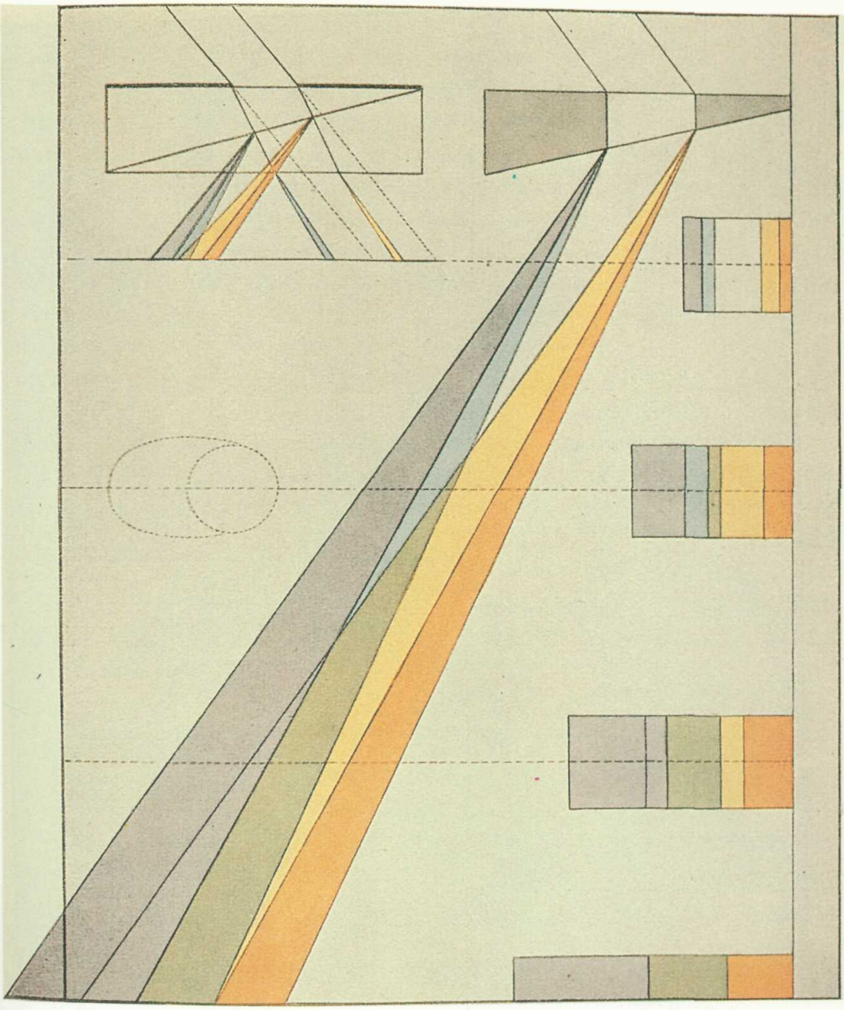


Plate V from *Theory of Color*. Refraction of a light form.

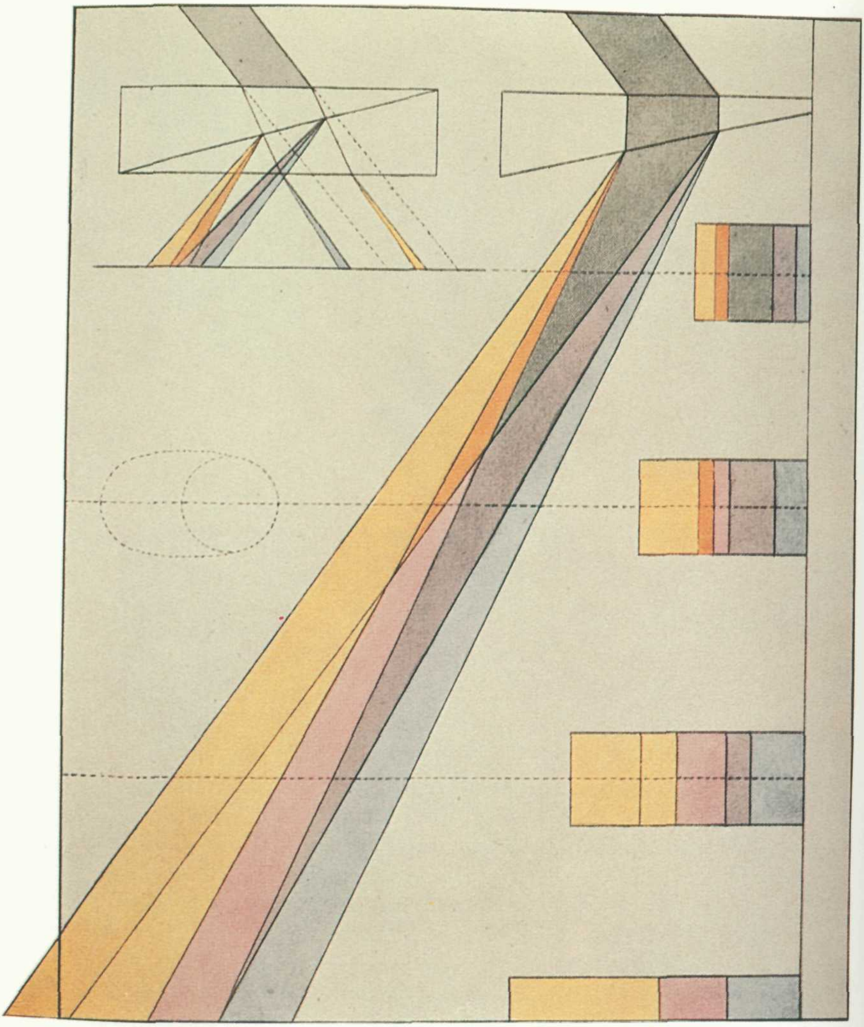


Plate VI from *Theory of Color*. Refraction of a dark form.

but the fringes will seem fainter. With gray on white we will see the same borders and fringes produced through the prism by black on white.

253. A sequence of gray tones arranged vertically will show only blue and violet at the borders, or only red and yellow, depending on whether the darkest shade is at the top or bottom.

254. A sequence of gray tones arranged horizontally will have the usual colors which depend on whether the series meets with a black or white surface above or below.

255. The reader may enlarge the plate illustrating this section for his own use.[48] Viewed through a prism, it will show him these phenomena at a single glance.

256. Most significant, however, is the observation and study of a gray form lying across two surfaces, one black and one white, with the line between the two running vertically through the form.

257. On this gray form the colors will appear in the usual way, but depending on the combination of light and dark they will be reversed along the dividing line. Where the gray seems light against the black surface, it will have red and yellow at the top, blue and violet at the bottom. Where it is dark against the white surface, we will see blue and violet at the top and the red and yellow border at the bottom. This observation is of importance for our next section.

XVIII. COLORED FORMS DISPLACED BY REFRACTION

258. A large colored surface shows as little prismatic color as a large black, white, or gray one; prismatic color will appear only where there is an accidental or intentional variation in light and dark. Thus our observations through the prism must be limited to a colored surface separated from a differently colored surface by a border; i.e., to colored forms.

259. Colors of any type resemble gray insofar as they seem darker than white and lighter than black. This quality of darkness (σκιερόν) in color was indicated earlier (§69) and will become increasingly important in our study. If we begin by looking through a prism at colored forms placed on black and white surfaces, we will find the same phenomena noted with gray surfaces.

260. Like a colorless form, the colored form will create an auxiliary form when displaced, and follow the same principles. The auxiliary form will retain its own character in regard to color and produce blue and blue-red on the one side, yellow and yellow-red on the other. Therefore in one case the phantom color of the border and fringe must be homogeneous with the real color of the colored form, while in the other the pigmented form and the apparent border and fringe may be heterogeneous. In the first instance the phantom form will coalesce with the real form, appearing to enlarge it; in the second, the real form

may be muddied, obscured and diminished by the phantom form. We will review the most striking demonstrations of this effect.

261. Let us turn to the illustrative plate provided for these experiments and look through our prism in the usual manner at the red and blue squares placed side by side on a black background.[49] Since both colors are lighter than their background, they will have identical colored borders and fringes at top and bottom, although to the observer's eye these will not appear with equal clarity.

262. Relative to black, red is lighter than blue. Therefore with red the colors of the borders will seem stronger than with blue, which acts here as a dark gray scarcely different from black (§251).

263. The red border on top will coalesce with the vermilion of the square; thus the red square will appear elongated a bit in an upward direction, while the yellow fringe extending down will merely lend the red surface more brilliance and become apparent only after closer observation.

264. On the other hand, the red border and yellow fringe will be heterogeneous with the blue square; hence a muddy red will appear at the border and a muddy green color will extend down into the square; superficial examination will give us the impression that the square has shortened a bit on this side.

265. At the lower edge of the two squares a blue border and a violet fringe will appear and yield the opposite effect. The blue border heterogeneous with the vermilion surface will muddy the yellow-red and produce a green of sorts; on this side the red will appear to have shortened and moved upward, and the violet fringe extending toward the black will go almost unnoticed.

266. On the other hand, the blue phantom border will coalesce with the blue surface and add to it rather than subtracting from it. This and the neighboring violet fringe will create the impression that the blue surface has elongated and moved downward.

267. The effect of the homogeneous and heterogeneous borders described here in detail is so powerful and strange that at first glance a casual observer will have the impression that the two squares have been pushed out of their horizontal alignment and displaced in opposite directions, the red square upward, the blue one downward. But this apparent effect will not deceive those who know how to observe methodically and connect or develop experiments systematically.

268. Our insight into this important phenomenon will be facilitated when we recognize that certain careful, even painstaking measures are necessary to create this piece of trickery. We must procure paper deeply colored with vermilion or the best minium for the red square, and with indigo for the blue square. Where they are homogeneous, the blue and

red prismatic borders will then merge undetectably with the form, and where they are heterogeneous they will muddy the color of the square without producing an obtrusive intermediate color. The red of the square must not become too yellowish, otherwise the apparent dark red border on top will be too obvious. But it should contain enough yellow, otherwise the change produced by the yellow fringe will be too noticeable. The blue may not be too light, or the red border will be visible and the yellow fringe will bring forth a green which is too obtrusive; it would also be impossible to pass off the violet fringe at the bottom as the displaced segment of a light blue square.

269. All this will be described in more detail when we discuss the apparatus for use in this section.[50] Each experimenter may prepare his own materials to create this illusion and then demonstrate that even here the colored borders do not escape the more careful observer.

270. In the meantime, the various other juxtapositions shown in our illustrative plate will serve to remove all doubt on this point for the attentive observer.

271. If we look at a square of white set next to our blue square on a black background, this white square (which replaces the red square used earlier) will show the two opposite borders at their most energetic. Here the red border extends up almost further than it did with the red square, even above the horizontal line of the blue square. The blue border on the bottom may be seen in its full glory against the white, but is lost where it coalesces with the color of the blue square. The violet fringe extending downward is much clearer against the white than against the blue.

272. We may now compare the carefully arranged sets of double squares found in our illustration, the red with the white, the two blue squares with one another, the blue with the red, and the blue with the white. We will then clearly see how these surfaces are related to their colored borders and fringes.

273. The borders appear even more clearly in relation to their colored forms when we view the colored squares and a black one on a white background. Here the above illusion will disappear completely and the effects of the borders will be as visible as ever. First let us view the blue and red squares through our prism. In both, the blue border now appears at the top. This border is homogeneous with the blue form; it unites with it and seems to raise it, except that the blue border is so light that it stands out too strongly. The violet fringe is also obvious enough as it extends down into the blue. This upper blue border is now heterogeneous with the red square; it is neutralized and scarcely visible. The violet fringe combined with the yellow-red of the form produces a peach-blossom color.

274. For the reasons given above, the upper borders of these squares seem unevenly aligned; but the lower borders will appear all the straighter since both colors, red and blue, are darker in comparison to white than they were light in comparison to black (this applies especially to blue). Thus the red border with its yellow fringe will appear quite visibly at the bottom of each form; under the yellow-red form it will appear in its full strength, and under the dark blue almost as it does under black. We can also observe this by arranging the forms one above the other and comparing their borders and fringes.

275. To make these experiments as effective and clear as possible we have placed squares of different colors in the center of the illustrative plate, with the boundary between black and white running vertically through them. In keeping with the principles we have encountered throughout, especially in colored forms, we will find these squares doubly colored at each border. The squares will look as if they had been torn apart and shifted up or down. Here we may recall the gray forms also viewed against a half-white, half-black background (§257).

276. In this instance two halves of a single form in one color show the same phenomenon observed earlier, almost as an illusion, with a red and blue square on a black background; i.e., the upward and downward displacement of two differently colored forms. Thus our attention is again drawn to colored borders and their fringes, and to the effects of their homogeneous and heterogeneous character in relation to the forms where they appear.

It may be left to the observer to compare the various shadings in the colored squares lying half on black, half on white. Here I will note only the absurd distortion apparently produced where red and yellow seem shifted upward on black but downward on white, and blue seems shifted downward on black but upward on white. All this, however, is in keeping with what we discussed at length above.

277. Now let the observer arrange the illustration so that these squares lying half on black, half on white, are in a horizontal row, with the black at the top and the white below. When he looks at the squares *through the prism he will note that the red square has been elongated* by the addition of two red borders. Upon close examination he will observe the yellow fringe on the red form, and the lower yellow fringe will be quite visible against the white.

278. The red border at the top of the yellow square is quite noticeable because the yellow stands out as being so light against the black. The yellow fringe coalesces with the yellow surface, but adds to its beauty; the border in red hardly shows at the bottom because the light yellow does not contrast enough with the white, although the lower yellow fringe will be evident enough.

279. In the blue square, however, the red border on top is barely visible and the yellow fringe spreads a dirty green down into the form, but the red border and yellow fringe at the bottom appear in vivid colors.

280. We may note in these cases that the red form is elongated by additions to both sides, while the dark blue one seems to be shortened on at least one side. The phenomenon will be reversed if we turn the illustration upside down so that the white section is on top and the black one below.

281. Then the homogeneous borders and fringes will appear at the top and bottom of the blue squares, making them seem larger and, in part, even more beautiful. Only close observation will let us see the borders and fringes as separate from the color of the surface itself.

282. With the illustration in this position, however, the yellow and red will be compressed by their heterogeneous borders and the effect of the real color will be degraded. The blue border on top of each is almost hidden, while the violet fringe appears as a beautiful peach-blossom color on the red, and a very pale one on the yellow. The two borders on the bottom are green, a dirty green on the red, vivid green on the yellow; the violet fringe is hardly noticeable under the red, but more visible under the yellow.

283. Every friend of nature should make it his duty to become thoroughly familiar with these effects, and not think it burdensome to subject a single phenomenon to so many modifying factors. These observations may be repeated endlessly with forms in different colors placed on and between variously colored surfaces. In every case, however, the close observer will note that adjoining colored squares seem displaced by the prism only because of the illusion created when homogeneous and heterogeneous borders are added to them. We will banish the illusion only if we are patient enough to do an entire series of experiments and show how they are consistent.

It might be possible to present the above experiments differently, but we have chosen to give them in detail for reasons which will become clear in due course. Although not unknown, these phenomena have *been thoroughly misunderstood; thus it was necessary to explore them* fully in anticipation of our later historical discussion.

284. Lastly, we wish to describe an apparatus with which the researcher will be able to observe these effects together in detail and, indeed, in their greatest glory.

In a piece of cardboard cut five identical holes about an inch square and in precise horizontal alignment. Cover the holes with five pieces of colored glass in the usual order: orange, yellow, green, blue, and violet. Fasten this cardboard over the aperture in a camera obscura so that the clear sky can be seen through the pieces of glass, or so that

the sun shines on them. We will find these to be extremely energetic forms. Let us view them through the prism and observe the phenomena we encountered in our experiments with painted forms; i.e., the borders and fringes (some enhancing, some detracting) and the resulting apparent displacement of each colored form out of the horizontal row.

What the observer will see here follows clearly enough from our previous account. Thus we will not review it again in detail, especially since we will have frequent occasion to return to these phenomena later.

XIX. Achromatism and Hyperchromatism

285. In the past much of what is regular and constant in nature was still considered merely an aberration, an accident. Little heed was paid to refractive colors which were considered an incidental effect arising from special circumstances.

286. After it had been shown that these colors always accompanied refraction, however, it was natural to consider them an integral and necessary part of refraction, and to believe that the degree to which they appear would simply depend on the degree of refraction, that the two go hand in hand.[51]

287. That refraction might be stronger or weaker was attributed largely, if not entirely, to varying degrees of density in the refractive medium (inasmuch as pure air, air filled with vapors, water, and increasingly dense glass will progressively augment so-called refraction, the displacement of the form). Thus there was no doubt that the appearance of color would intensify to the same extent, and in combining various media to reduce refraction it was deemed certain that color would appear when refraction was present, but that when the color disappeared the refraction would also be canceled.

288. Later, however, it was discovered that this presumed correlation was not valid, that two media could displace the form equally and yet produce very dissimilar color fringes.

289. It was found necessary to postulate a chemical quality in addition to the physical one long held to be the source of refraction (§210). We intend to pursue this question further when we come to considerations of a chemical nature, and to include a fuller description of this important discovery in our history of color theory. For the present the following shall suffice.

290. It is a remarkable fact that in media of equal or almost equal refractive power an increase or decrease in the appearance of color may be produced by chemical treatment, an increase through acids, a decrease through alkalis. By adding metallic oxides to common glass we can greatly increase the appearance of color through the glass with-

out any noticeable change in refraction. Obviously the opposite effect, a decrease, is produced by an alkali.

291. The first glasses used after this discovery were called flint glass and crown glass by the English. The increased appearance of color is a property of the former, and the diminished appearance a property of the latter.

292. In our present discussion we will use these two expressions as technical terms and assume that refraction is the same in both, but that the appearance of color in flint glass is a third greater than that in crown glass. We have also provided the reader with a drawing which illustrates this in a somewhat symbolic way.[52]

293. Let us imagine five white squares lying between parallel lines *ab* and *cd* on a black surface divided for the sake of convenience into a grid. Square 1 will appear to the naked eye undisplaced from its original position.

294. Square 2, however, will move three squares when viewed through a prism of crown glass (*g*), and display a color fringe of a certain width. Square 3 will likewise be moved three squares by a prism of flint glass (*h*), so that it displays a color fringe a third wider than that of square 2.

295. Let us also imagine that square 4 (like square 2) is first moved down three squares by crown glass, but that it is then moved back up to its original position through a reversed prism of flint glass (*h*).

296. Here refraction has indeed been canceled by the two prisms. But in displacing the form by three squares on the grid, prism *h* has produced a color fringe one third broader than that belonging to prism *g;* hence there will be a residual color fringe even though the refraction is gone. This color fringe will be affected by the direction of the apparent displacement created by prism *h*, and thus the colors will be the reverse of those seen in squares 2 and 3 (which were moved downward). We have called this excess of color *hyperchromatism*, from which the quality of achromatism may be directly deduced.

297. Let us assume that square 5, like square 2, has been moved down three squares from its original position by a prism of crown glass (*g*). Simply by decreasing the angle in a prism of flint glass (*h*) and reversing it on top of prism *g*, we may seemingly raise square 5 two squares. The hyperchromatism of the first instance will disappear and the form will appear without color even though it has not returned to its original position. If we extend the sides of the two prisms combined under square five, we will see that there is actually a single prism; if we imagine the lines to be curved we will arrive at an optical lens which is the basis for the achromatic telescope.

298. A small prism made in England of three separate prisms is especially useful for these experiments. It is to be hoped that someday

our own German opticians will be able to supply researchers with this essential instrument.

XX. ADVANTAGES OF THE SUBJECTIVE EXPERIMENTS TRANSITION TO THE OBJECTIVE EXPERIMENTS

299. Through a series of subjective experiments we introduced the color phenomena associated with refraction and reached the conclusion that we may find the source for these phenomena in the principles of turbid media and double images.

300. Since observation and investigation are of primary importance in any discussion about nature, these subjective experiments are all the more desirable because of the ease and convenience with which they can be done. Any interested layman can obtain the necessary materials without great expense of time or money, and even make many of them himself if he knows something about working with cardboard. All he needs are a few pieces on which black, white, gray, and colored forms alternate against a light and dark background. They will remain in place while he makes a leisurely inspection of the effects around the forms, viewing them from near or far, and observing closely the progressive changes in the phenomenon.

301. Furthermore, the phenomena can be observed well enough through small prisms with slight imperfections in the glass. Other useful instruments of glass will be given a full description in our section on materials.

302. Another major advantage of these experiments is that they may be done at any time of day and in any room, no matter which way it faces. It is not necessary to wait for sunshine, a boon but infrequently granted to the observer in northern climates.

Objective Experiments

303. Objective experiments necessarily require sunshine. But even when the sun is shining, it may not always be in the position desired for our instruments. At times it will be too high, at times too low, and only briefly will it lie within the compass of even the best-placed rooms. The sun moves during our observation and our instrument must track it, often introducing an element of uncertainty into our experiments. When the sun shines through a prism it will reveal every imperfection, every line and bubble in the glass, which will confuse, muddy, and discolor the effect.

304. Yet we must become equally familiar with both types of experiment. They seem to be opposites, but they always parallel one another. What one shows, the other shows as well, yet each type has its

own characteristics, thus revealing certain effects of nature in more than one way.

305. Some significant phenomena may also be produced by combining subjective and objective experiments. Another advantage of objective experiments is that we can show them in a diagram which lays open the relationships in the phenomenon. We will therefore not hesitate to present our objective experiments so that the phenomena coincide throughout with those in our subjective experiments. Beside the paragraph numbers of the next section we will indicate the number of the corresponding paragraph in parentheses. We must also assume that the reader is familiar with the illustrative plates, the researcher with the materials, so that the twin phenomena under discussion may really be present for them in one way or the other.

XXI. REFRACTION WITHOUT THE APPEARANCE OF COLOR

306 (§§195, 196). That refraction may occur without creating color is not as easy to demonstrate in objective experiments as in subjective ones. We have unbounded areas which we can view through the prism to show that no color will arise in the absence of a boundary, but we have no unbounded source of light to let work on the prism. Our light comes to us from bounded bodies, and the sun, which provides most of our objective prismatic effects, is itself only a small form, a bounded source of light.

307. But to the extent that we merely observe the center of the surface instead of its boundaries we may treat any larger opening through which the sun shines, any larger medium which catches the sunlight and changes its direction, as unbounded.

308 (§197). A large water prism in the sunlight will refract a bright area upward onto a surface opposite it, and the center of this illuminated area will be without color. We can also do this experiment with narrow-angled glass prisms. Even glass prisms having a refractive angle of sixty degrees will produce this effect if we bring the surface close enough.

XXII. CONDITIONS FOR THE APPEARANCE OF COLOR

309 (§198). This illuminated area will appear refracted, displaced, but without color, although we will see the appearance of color at its horizontal boundaries. We will now demonstrate further that this color arises from the displacement of a form.

The source of light at work here is bounded, and the sun, in its shining and radiating, has the effect of a form. No matter how small the aperture in the shutter of a camera obscura, an image of the entire sun will enter. The light streaming from its disk will intersect in the smallest aperture

and form an angle corresponding to the apparent diameter of the sun. On the outside will be a cone with its apex at the opening, and on the inside this apex will open out again to produce a round image which may be captured on a surface; this image will become larger as the distance to the surface increases. Together with the other forms in the outer scene it will appear inverted on a white surface opposite it in a dark room.

310. Note how little is said here of single sun rays, bundles and fascicles of rays, ray cylinders and beams, or the like.[53] As an aid to representing certain things schematically we may suppose the incident sunlight to be parallel, although we should keep in mind that this is only a fiction. Such a fiction is certainly permissible where the gap between the fiction and the real phenomenon is insignificant, but we must be careful to avoid making the fiction itself into a phenomenon and then applying our research to this imaginary phenomenon.

311. We may make the aperture in the window shutter as large as we wish, give it a shape which is round or square, even open the shutter altogether and let the sun shine into the room through the whole window—the increase in the area it illuminates will always agree with the increase in the angle formed by its diameter. Thus the area illuminated by the sun through even the largest window will equal only the sun's form plus the width of the aperture. We will have occasion to return to this point later.

312 (§199). When we capture the form of the sun with a convex glass we draw it together to a focus. According to the principles described above, a yellow fringe and a yellow-red border will appear in the image formed on a sheet of white paper. Because the image is blinding and uncomfortable, however, this experiment is best done with the form of the full moon. When this is focused through a convex glass the colored border will appear in its full glory, for the moonlight itself is a moderate light, and thus all the more easily produces the color brought forth by the moderation of light. At the same time, it will have only a soft and pleasant effect on the eye of the observer.

313 (§200). When we capture a luminous form with a concave glass it will be magnified and therefore expand. Here the image appears bounded in blue.

314. With a convex glass it is possible to create these two opposite effects simultaneously or in succession. This may be done simultaneously by gluing an opaque disk in the center of the convex glass and then capturing the form of the sun. In this case the luminous form will be contracted, as will its black center, and thus opposite color effects will arise. We may also observe these opposites successively by drawing the luminous form to a focus to produce yellow and yellow-red, and then letting it expand again beyond the focus to form a blue boundary.

315 (§201). What we found in our subjective observations will also

apply here: blue and yellow will appear across the white surface and at its edge, while both colors will take on a reddish appearance where they extend across the black surface.

316 (§§202, 203). These basic phenomena were fundamental in our earlier subjective experiments and will likewise be found in every objective experiment to follow. The process is the same: a light border is moved toward a dark surface, a dark surface toward a light border. The borders must shift and seemingly thrust across one another in these experiments as in our earlier ones.

317 (§204). Thus when we admit the sun's form into our dark room through any aperture and pass it through a prism with its refracting angle downward as usual, the radiant form will not fall in a straight line to the floor, but be refracted upward onto a vertical surface. Here we must pause to note the contrast between the subjective and objective displacement of the form.

318. A form above us will be shifted downward when viewed through a prism with its refracting angle pointed down, whereas an incident luminous form will be shifted upward by the same prism. What is only outlined here for the sake of brevity may be deduced easily from the principles of refraction and elevation.

319. With a luminous form displaced in this way the color fringes will also travel as indicated in the above principles. The violet fringe leads the way and therefore moves upward in objective displacement, downward in subjective displacement.

320 (§205). The observer may also demonstrate the coloration produced along a diagonal when two prisms displace the form. This was noted clearly in subjective displacement, but here it is necessary to have a prism with an angle of only a few (e.g., fifteen) degrees.

321 (§§206, 207). Here, too, the form is colored in the direction of its movement. This may be seen by making a medium-sized square opening in a window shutter and passing the luminous form through a water prism, first with the borders in a horizontal and vertical direction, then diagonally.

322 (§208). This will show once more that the boundaries must move across one another and not in parallel.

XXIII. CONDITIONS UNDER WHICH THE APPEARANCE OF COLOR INCREASES

323 (§209). Here, too, increased displacement of the form will produce a stronger appearance of color.

324 (§210). An increased displacement occurs:

1) when the angle between the incident luminous form and media with parallel sides becomes more oblique.

2) when the sides of the medium are no longer parallel but form an angle which is to some degree acute.

3) when the mass of the parallel or angled medium is increased, partly because the displacement of the form becomes stronger, and partly because a property connected with the mass produces an effect.

4) when the surface displaying the image is moved further from the medium of refraction so that the emerging colored form must travel a greater distance.

5) there is always an effect caused by the chemical property described more fully in the section on achromatism and hyperchromatism.

325 (§211). An advantage of the objective experiments is that we can find external means to demonstrate the progress of the phenomenon as it develops successively, and then clarify it with diagrams. We were not able to do this with the subjective experiments.

326. On a surface placed at different distances we can observe the luminous form emerging from the prism and the increasing appearance of color in it; thus we can show cross sections of this cone with an elliptical base. But the most beautiful way to make the entire course of the phenomenon visible is to scatter a cloud of fine white dust into the form's path through the dark room; this is best done with fine, perfectly dry hair powder. The phenomenon with its various degrees of coloration will be caught by the white particles and revealed to the eye in its whole length and breadth.

327. We have also prepared diagrams showing the phenomenon from its inception, and included them among our illustrative plates.[54] These make clear why the luminous form is colored so much more strongly by prisms than by media with parallel sides.

328 (§212). At each of the two opposite boundaries an opposite effect arises in a narrow angle, and widens along the extension of this angle as it traverses the room. In the direction of the luminous form's displacement a violet fringe advances into the dark, while a narrow blue border remains at the boundary. From the other side a yellow fringe advances into the light and a yellow-red border remains at the border.

329 (§213). Here we must note the movement of the dark toward the light and the light toward the dark.

330 (§214). For a long while the center of the form remains without color, especially with media of little density and mass. At last the opposite fringes and borders will reach one another, and a green color will appear in the center of the luminous form.

331 (§215). Objective experiments often use the luminous form of the sun, but seldom a dark form. We have found a convenient way to arrange such an experiment. Let us place our large water prism in the sunlight and glue a round cardboard disk to its outer or inner face. The color effect will occur at the borders of the disk and proceed in accord

with the usual laws; the borders will expand proportionately, and in the center purple will appear. We may add a square near the disk to corroborate the principle stated and explained several times earlier.[55]

332 (§216). We may remove these dark forms from our prism (always taking care to clean the glass thoroughly), and hold a rod (e.g., a thick pencil) up before the center of the horizontal prism. We will then produce a complete merger of the violet fringe and the red border, and see only three colors, the two outer ones and the one in the middle.

333. We may also cut a long horizontal slit in a piece of cardboard, slide the cardboard in front of the prism, and let the sunlight shine through it. We will produce a complete union of the yellow fringe and the blue border across the light, and see only yellow-red, green, and violet. How this comes about is further described in the explanation of the illustrative plates.

334 (§217). Thus the prismatic phenomenon is by no means full and complete when the luminous form emerges from the prism. At that point the presence of opposites merely makes us aware that it has begun. It then grows; the opposites unite and interpenetrate thoroughly. The cross section of this phenomenon will change every time the surface on which it is shown moves away from the prism; this makes it impossible to speak of a constant sequence or fixed proportion in color. Here the reader and the researcher will want to turn to nature and to our illustrative plates, themselves true to nature; a review of our explanation and complete instructions for our experiments have been appended to these plates.

XXIV. SOURCE OF THE FOREGOING PHENOMENA

335 (§218). We have already provided a full explanation of this source in connection with our subjective experiments. What applied then holds true now as well. It will not be necessary to repeat our entire discussion to show that these parallel effects may be attributed to the same source.

336 (§219). Above we have shown in detail that our objective experiments also involve forms. No matter how small the aperture, the form of the sun's full disk will always pass through it. No matter how large the prism in open sunlight, the sun's form is always what is bounded at the edges of the refractive surfaces, thus producing auxiliary images of these boundaries. We may cut a variety of shapes in a piece of cardboard and slide it in front of the water prism; these various forms, now displaced by refraction, will still be the source of the colored borders and fringes and reveal perfect auxiliary forms in them.

337 (§235). Our subjective experiments used strongly contrasting forms to produce a vivid appearance of color. The colors in our objective experiments are even more vivid and resplendent because the energy

of the sun's form is greater than any we know, and thus the auxiliary form is also strong, splendid, and brilliant despite its secondary, turbid, and darkened state. The colors the sun casts through a prism on any object are accompanied by a powerful light, for they have the primal light with all its energy as their apparent background.

338 (§238). Anyone who has followed our argument thus far will understand why we can say that these auxiliary forms, too, are turbid, and that their source lies in the principles of turbid media. This will be especially obvious to those who have the instruments needed to investigate the clarity and vigor with which turbid media act.

XXV. Decrease in the Appearance of Color

339 (§243). In the subjective section we were able to offer a concise description of the decrease in color. Here we may be even more concise and refer the reader to the clear depiction given earlier. We must, however, call attention to a point which is significant as a major theme in our entire presentation.

340 (§§244–247). A decrease in the prismatic effect must be preceded by a development of the same effect. When the surface is far enough from the prism, blue and yellow will finally disappear from the colored form of the sun; they will merge fully and we will see only yellow-red, green and blue-red. As the surface is brought closer to the refractive medium, yellow and blue will reappear and we will see the five colors *with their gradations. When the surface is brought even closer, yellow* and blue will separate fully, the green will disappear, and between the colored borders and fringes the form will appear colorless. The closer the surface comes to the prism, the narrower these borders and fringes will become, until finally they are reduced to nothing at and on the prism.

XXVI. Gray Forms

341 (§248). Gray forms proved to be of great importance for our subjective experiments. Their auxiliary forms show through their weakness that they are always a product of principal forms. To continue the parallel in our objective experiments it will be convenient to put a rather heavily frosted glass over the aperture through which the sun's form enters. The subdued form thereby created will produce much duller colors on our surface than those derived directly from the disk of the sun, and thus even the extremely energetic form of the sun will create only a weak auxiliary form in keeping with its subdued nature. Of course, this experiment merely reconfirms what we already know.

XXVII. COLORED FORMS

342 (§260). There are several ways to create colored forms for use in our objective experiments. First, we can put colored glass over an opening to produce an immediate colored form. Second, we can fill the water prism with a colored liquid. Third, we can project the emphatic colors produced by a prism through small openings proportionately spaced in a thin piece of metal, and thereby prepare small forms for a second refraction. This last method is the most difficult because the continual advance of the sun makes it impossible to hold such a form or keep it in the desired direction. The second method also has its drawbacks because not all colored liquids can be made perfectly bright and clear. Thus the first method is preferable, all the more so because physicists have long considered the colors created by the sun through a prism, those produced through liquids and glasses, and those already fixed on paper or cloth as equally effective for the purpose of demonstration.

343. Since we are merely concerned with providing a colored form, the large water prism mentioned above will be most suitable. Its large surfaces (which transmit light without adding color) may be covered with a piece of cardboard in which various openings have been cut to produce different forms and, as a result, different auxiliary forms. We may fasten pieces of colored glass over the openings in the cardboard to observe the effect of objective refraction on colored forms.

344. Here we may use the cardboard with colored pieces of glass described earlier (§284); it must be made to fit into the grooves of the large water prism. When the sun shines through the prism we will see the colored forms refracted upward, each with its own fringes and borders. In some forms these fringes and borders will be quite distinct, while in others they will mix with the color of the glass itself and enhance or degrade it. Thus any observer can prove for himself that we are again concerned with the simple phenomenon described earlier in our detailed subjective and objective discussions.

XXVIII. ACHROMATISM AND HYPERCHROMATISM

345 (§§285–290). After the extensive description above we need only a brief indication of how objective hyperchromatic and achromatic experiments may be done, especially since we assume that the observer has at hand the compound prism mentioned earlier.

346. Using a prism of crown glass with a narrow angle of only a few degrees will refract the form of the sun upward onto a surface; the borders will be colored according to the usual rule, with violet and blue above and on the outside, yellow and yellow-red below and on the inside. Since the refracting angle of this prism points down, we will

combine it with a second prism of appropriately shaped flint glass with its refracting angle up. The form of the sun will be returned to its original position, where it will show some color caused by the excess color production in the prism of flint glass refracting it downward. This coloration will follow the rules of downward refraction, with blue and violet below and on the outside, yellow and yellow-red above and on the inside.

347. If we use a third prism proportionately shaped of crown glass to move the whole form up slightly, the hyperchromatism will be canceled and the form of the sun will appear displaced but without color.

348. We may do this experiment step by step using an achromatic telescope consisting of three lenses (if we do not mind removing the lenses from the optician's mounting). The two convex lenses of crown glass (which draw the form to a focus) and the concave lens of flint glass (behind which the form is expanded) will show the usual colors at the border. A convex lens combined with the concave lens will show colors in keeping with the principles of the latter. But whether we draw the sun's form to a focus or let it expand again beyond the focus, no colored borders will be seen when we use all three lenses together; thus the achromatism intended by the optician will be restored.

349. Crown glass, however, always has a greenish color, so that a somewhat greenish cast will creep in, especially with strong lenses or large ones. Under certain circumstances the complementary purple color may also be present (although we have never observed it despite repeated experiments with several lenses). The oddest explanations have been offered for this. Because it was necessary to prove theoretically that achromatic telescopes were impossible, a certain sense of satisfaction was taken from the fact that such a radical improvement could be disputed.[56] This will be dealt with later in the history of this invention.

XXIX. Objective and Subjective Experiments in Combination

350. Above we saw the opposite effects of refraction in its objective and subjective aspects (§318). It follows that a combination of these experiments will produce mutually contradictory effects which cancel one another out.

351. Project the form of the sun on a wall through a prism placed horizontally. If the prism is long enough to let the observer look through it at the same time, he will see the form which was previously raised by objective refraction lowered again to the spot where it would have appeared had there been no refraction.

352. Here we find an important phenomenon, one which derives

inevitably from natural law. As we have so often observed, the colored form of the sun thrown objectively on the wall is not a fixed or immutable phenomenon. Thus the procedure mentioned above will not only lower the form as we look at it, but also rob it completely of its borders and fringes, thereby restoring it to a circular shape without color.

353. By using two identical prisms placed side by side, we can project the form of the sun through one while we look through the other.

354. If the observer approaches the wall with the second prism the form will move up again and show a progressive increase in color corresponding to the principle of the first prism. The observer may then back away from the wall until the form is returned to the neutral point. As he steps back even further, the form, previously round and colorless, will continue to move down, and its coloration will follow the opposite principle. By looking both through the prism and directly at the refracted image on the wall he will see a single form colored according to objective and subjective principles.

355. The variations on this experiment are obvious. The refracting angle of the prism used to raise the form of the sun objectively may be greater than that of the prism through which the observation is made; the observer must then step much further back if he wishes to lower the colored form on the wall far enough to remove its color, and vice versa.

356. It is easy to see that we may also demonstrate achromatism and hyperchromatism in this way; it will be left to the reader to pursue these experiments. Later we will describe other complex experiments which use prisms combined with lenses, thus mixing objective and subjective effects in various ways. These effects will then be traced back to the phenomena now so familiar to us.

XXX. TRANSITION

357. In reviewing the above description and explanation of dioptric colors we feel no regret at presenting them in such detail, or putting them first instead of following the order we ourselves laid out for physical colors. But here we will offer a justification for this to our readers and fellow scientists.

358. To justify presenting the principles of dioptric colors (especially those of the second class) in such overwhelming detail, we must note the following. A discussion of any area of knowledge must be related partly to the inner necessities of its subject and partly to the needs of the age in which the presentation is made. In our discourse it was necessary always to keep an eye on both considerations. On the one hand, it was our intention to follow a well-proven method in presenting all

our observations and findings. On the other, we had to consider the need to present the phenomena according to their natural development and in an order truly based on empirical observation, for many of these phenomena are well known but misunderstood and often placed in the wrong context. Our later polemic and historical discourse will refer to the overview provided by this thorough preliminary study. This is why greater detail is required; it is really a concession to the needs of the present time. It might be possible to shorten this entire presentation in a later age when the simple is recognized as simple, the compound as compound, when the primary and foremost is seen for what it is, and the secondary and derivative for what it is. If this task eludes us we may leave it to the untrammeled activity of our contemporaries and successors.

359. In regard to the order of the sections we should remember that even related natural phenomena do not occur in any real order or consistent sequence, but are produced by actions having a narrow effect. It little matters which phenomenon one considers first and which last, for the point is to have as many as possible present so that we can take a unified approach in arranging them, partly in keeping with their nature, and partly as dictated by our method and the requirements of convenience.

360. In the present case, however, we may state that dioptric colors deserve first consideration among the physical colors because of their striking brilliance and general importance, and because the explanation of their source requires us to present a number of points which will simplify later discussion.

361. Until now light has been viewed as a kind of abstraction, an entity existing and acting by itself, modifying itself to a degree and creating color out of itself with little cause. The task remaining, the goal before us, is to divert the scientist from this way of thinking, to make him aware that prismatic and other effects involve not an unbounded modification of light but a bounded modification, a form consisting of light—indeed, forms in general, whether light or dark.

362. We have now learned enough about what occurs in dioptric colors, especially those of the second class (i.e., refractive colors). This will serve as an introduction to what follows.

363. Catoptric colors remind us of physiological colors, except that we can ascribe a more objective quality to the former and therefore feel justified in including them among the physical colors. It must be noted, however, that we will once again be considering a light-form here, not light as an abstraction.

364. If we bring a good grasp of these principles to paroptic colors we will be surprised and pleased to find ourselves once more in the realm of forms. The shadow of an object will prove particularly in-

structive as a secondary form which accompanies the object exactly like any other secondary form.

365. But instead of anticipating these later discussions we will proceed with our step-by-step presentation as planned.

XXXI. CATOPTRIC COLORS

366. By catoptric colors we mean those colors which appear as the result of reflection. We will assume both the light and the surface reflecting it to be completely colorless; in this sense these effects belong to the physical colors. They arise as the result of reflection, just as dioptric colors of the second class appeared as the result of refraction. We will now turn from these general statements to specific examples, and discuss the conditions necessary for the production of these phenomena.

367. When we unspool a fine steel wire, let it spring back naturally into a tangled coil, and place it in window light, the raised coils and convolutions will catch the light but seem neither radiant nor colored. In direct sunlight, however, these highlights will condense to a point and we will see a small, radiant form created by the sun. Viewed close up, this form will display no color, but when we step back and look at the reflection from a distance we will see many small, multicolored images of the sun. Although green and purple appear most prominently, closer observation will reveal the presence of the other colors as well.

368. When this effect is viewed through a pair of opera glasses the colors will vanish along with the expanded radiance in which they appeared, and we will see only small luminous points, repeated images of the sun. This tells us that the effect is subjective in nature, and that the phenomenon is related to those described earlier as radiant halos (§100).

369. But we can also demonstrate this phenomenon objectively if we put a piece of white paper under a moderate aperture in a camera obscura and hold the tangled wire opposite the paper so that the sunlight shines through the aperture onto the wire. The sunlight will strike on and into the coils of the wire, but will not appear in a point as it does to the concentrating power of the eye. Because the paper can catch the reflection over its entire surface, the sunlight will appear in hairlike lines which are also multicolored.

370. This experiment is purely catoptric, for it is inconceivable that the light has penetrated the surface of the steel and been altered there in some way. It is clear that this is only a reflection. Insofar as this reflection is subjective, it is related to the principles of fading lights and lights with a weak effect; insofar as we can make it objective, it

points even in its most subtle effects to something with a real existence external to us.

371. We have seen that this phenomenon requires not just light, but an energetic light; not just a generalized abstraction, but a bounded light, a light-form. We will demonstrate this point further in related cases.

372. A polished silver plate in the sun will produce a blinding glare without color. But if we scratch the surface lightly and view the plate from a certain angle, iridescent colors will appear, especially green and purple. This phenomenon also appears in metals which are chased or engraved with a guilloche pattern. It must be observed, however, that the iridescence appears only when a form of some kind, a combination of dark and light, is also at work in the reflection; thus a noticeable effect will be created by a window bar, the bough of a tree, or any accidental or intentional obstacle. We can also objectify this effect in a camera obscura.

373. We may etch this polished silver plate with aquafortis so that the underlying copper is attacked and the surface becomes somewhat rough. The sun's form reflected in the plate will shine back from each infinitely small, raised point, and the surface of the plate will appear in iridescent colors. Similarly, when we hold a sheet of unglazed black paper in the sunlight and look at it closely, we will see the tiniest portions of it gleaming iridescently in the most vivid colors.

374. All these observations point to the same set of conditions. In the first case the light-form reflects from a narrow line, in the second it apparently reflects from sharp edges, in the third from very small points. Each requires a strong light which is bounded. It is equally necessary for all these appearances of color that the eye be at an appropriate distance from the reflecting points.

375. When observed under the microscope the effect will greatly increase in power and radiance. We will then see the tiniest portions of the sun-lit object shimmering in these colors of reflection, related to the colors of refraction but enhanced here to the highest degree of splendor. In such cases a vermiform iridescence may be observed on the surface of organic objects; this will be discussed in detail later.

376. Lastly, the colors appearing most frequently in reflection are purple and green. From this we may surmise that the effect, especially with striation, consists of a subtle purple line bounded on either side with blue and yellow. Where the lines come very close together, the area between them appears green, a phenomenon we will encounter more than once as we proceed.

377. Colors of this type are often encountered in nature; we believe that the colors of the spider's web belong in the same class as those

reflected from the steel wire. The opacity of the web, however, is more difficult to verify than that of the steel wire; attempts have therefore been made to classify these colors as refractive.

378. In mother-of-pearl we will observe extremely fine organic fibers and lamellae arranged side by side. Like the scratched silver above, these will give rise to various colors, especially purple and green.

379. The changing colors in bird feathers also deserve mention here, although in any organic object we must suppose a chemical basis as well as an adaptation of the color to the object. We will discuss this later in the section on chemical colors.

380. It will be readily agreed that the effects found in objective halos are also closely related to catoptric phenomena, although refraction undeniably plays a part as well. We will offer a few observations here, although after completing our survey of theoretical considerations we will be in a better position to apply our general knowledge to individual phenomena.

381. We will begin by returning to those yellow and red circles produced on a white or grayish wall by a candle set next to it (§88). Light reflected from an object will be subdued, and the subdued light will create the sensation of yellow and then of red.

382. Our candle sheds a strong illumination on the wall surface closest to it. The further the illumination spreads the weaker it becomes, although it remains an effect of the flame, an extension of its energy, an expanded effect of its form. These circles might therefore be called boundary forms; they mark the edge of the activity and yet present only an expanded flame-form.

383. When there is a white glow in the sky around the sun because of a slight haze in the atmosphere, or when haze or clouds surround the moon, the radiance of the disk will be mirrored in them. We will then see single or double halos which are large or small, sometimes quite large, often colorless, and occasionally colored.

384. I observed a very beautiful halo around the moon on November 15, 1799, a day when the barometric pressure was high although the sky was cloudy and filled with haze. The halo was fully colored, and the circles were arranged around the light as in a subjective halo. It became clear that this was an objective effect after I blocked out the moon's form and could still see the full halo.

385. The variation in the size of halos apparently depends on the distance between the haze and the observer's eye.

386. A windowpane breathed upon lightly will enhance the brilliance of subjective halos and objectify them to some extent. It might therefore be possible to discover more about them by this simple means during winter, when the cold provides a quick way to produce frost.

387. The phenomenon of so-called mock suns demonstrates why we

are justified in insisting on the form and its effects as the basis for these circles. Such companion forms are always present at certain points on the halos and circles, and are merely a more defined representation of what is occurring in a general way throughout the circle. All this will be more easily discussed in connection with the phenomenon of the rainbow.

388. Lastly, we need only indicate that catoptric and paroptic colors are related.

We will use the term paroptic colors for colors created when light passes across the edge of a colorless opaque object. Their close relationship to dioptric colors of the second class will be evident to those who believe with us that refractive colors appear only where there are edges. The following section will clarify the relationship between catoptric and paroptic colors.

XXXII. Paroptic Colors

389. Paroptic colors were previously called perioptic because light was thought to create an effect surrounding the object, as it were; this effect was attributed to a certain ability of the light to bend toward the object and away from it.

390. These colors can also be classed as either objective or subjective since some appear externally, as though painted on the surface, while others appear directly on the retina. In this section it will be best to consider the objective colors first, for the subjective ones are so closely related to certain other effects we have studied that it is difficult to keep them separate.

391. These colors are called paroptic because light must pass across an edge to produce them. But they will not always appear when light passes across an edge; other conditions must also be present for color to appear.

392. We will note that here, too, light does not work as an abstraction (§361), for the sun must shine across an edge. All the light streaming from the sun's form creates an effect across the boundary of an object and causes shadows. At these shadows, within them, we will become aware that color is present.

393. Let us begin by making our observations in the fullest light. We will take the observer outdoors before leading him into the confines of a dark room.

394. Anyone strolling in a garden or along a smooth path on a sunny day will notice that his shadow is sharply defined only on the ground near his foot. Further up, especially near his head, the shadow will melt away into the bright surface. Since the sunlight radiates not only from the center of the sun, but also crosswise from each end of this

luminous star, an objective parallax is created which produces a semi-shadow on either side of the object.

395. When he raises his hand the stroller will observe the two semi-shadows of each finger spreading outward while the principal shadow narrows inward. Both effects result from the intersecting light.

396. These experiments may be repeated or varied in front of a smooth wall by using rods of different diameters, or spheres. We will always find that the further the object is from the surface, the more the weak double shadow spreads and the strong principal shadow narrows, until the latter seems to be obliterated entirely and the double shadows finally become so weak that they almost disappear; at an even greater distance the double shadows will become imperceptible.

397. It is easily proven that this is the result of light crossing over itself, for the shadow of a pointed object will clearly show two points. Thus we must never lose sight of the fact that here the entire form of the sun is at work, producing shadows, transforming them into double shadows, and finally obliterating them.

398. Instead of solid objects we may use a row of sharply cut openings in various sizes, and let the sun shine through them onto a surface some distance away. We will find that the bright form produced on the surface by the sun is larger than the opening through which the sun is shining, that one edge of the sun shines through the side of the opening opposite it although its other edge is blocked. Thus the borders of the bright form are more weakly illuminated.

399. We will find that the bright form on a surface nine feet from a square opening of any size is an inch larger on each side than the opening. This corresponds closely with the angle of the sun's apparent diameter.

400. It is natural that the illumination at the borders should gradually become weaker, since in the end only a minimal amount of light from the edge of the sun can work crosswise through the edge of the opening.

401. Here we see once more how important it is in our observations to avoid assumptions about parallel rays, bundles and fascicles of rays, or anything else of this hypothetical sort (§309, 310).

402. We may instead consider the shining of the sun, or of any light, as an infinitely repeated mirroring of the defined light-form. From this we may deduce that the sun shining through a square opening will create a round form at a certain distance which will depend on the size of the opening.

403. By repeating our earlier experiments with openings of various sizes and shapes we will be able to observe this effect on a surface at the required distance. Here we will invariably note that no color appears when the light is full and the sun merely shines across an edge.

404. We will therefore turn to experiments with subdued light since

such light is necessary for the appearance of color. Let us make a small opening in the window shutter of a dark room and on a piece of white paper capture the sun's form, which will intersect and cross as it passes through the opening. The smaller the opening, the dimmer the light; this is natural since the paper will not be illuminated by the whole sun but only by several points of it, only by a part of it.

405. Upon examining this dim sun-form we will discover that it becomes increasingly dim toward the edges and is bounded by a distinct yellow fringe; this fringe is most distinct when a mist or translucent cloud passes in front of the sun, thus subduing and moderating its light. Does not this remind us of a halo on the wall and the glow from the candle next to it (§88)?

406. When we look more closely at the sun-form described above we will find that it does not end at this yellow fringe: we will see a second, bluish circle, if not a halo-like repetition of the color fringe. In a very dark room we will observe that part of the image is the bright sky around the sun; on the paper we will see the blue sky, even the entire landscape, once more proving that the sun is involved here only as a form.

407. If we use a somewhat larger square opening so that the sun does not immediately produce a round image, we will be able to make careful note of the semishadows cast by each edge, the meeting of the shadows at the corners, and their coloration (similar to that of the round opening mentioned above).

408. A light shining parallactically has now been subdued by its passage through a small opening, but has not lost its parallactic quality; thus it is still capable of producing double shadows of objects, although with subdued effect. Earlier observers noted how these double shadows follow one another in a succession of various light and dark, colored and colorless circles, and produce repeated, almost innumerable halos. These were often depicted in drawings and engravings; needles, hairs, and other thin objects were placed in the subdued light, then the many halo-like double shadows were observed and attributed to light being bent in and out. Thus an explanation was sought for the obliteration of the central shadow and the appearance of light in the place of dark.

409. To begin with, however, we will stand by our assertion that these, too, are parallactic double shadows appearing with colored fringes and halos.

410. After having observed, examined, and clarified all this, we may proceed to the experiment with knife blades which we can characterize as simply the convergence and parallactic crossing of the semishadows and halos already familiar to us.[57]

411. Lastly, we must observe the results of those experiments with hairs, needles, and threads in the half-light brought forth by the sun as

well as in the half-light created on the paper by the blue sky. In this way we will gain an increasing mastery of the real principles underlying this phenomenon.

412. The main point of these experiments is to demonstrate the parallactic effect of a shining light; we can make this point clearer by using a pair of lights to bring the two shadows together or separate them completely. During the day this can be done with two openings in the shutter of the window, and at night with two candles. In fact, when opening or closing the window shutters we often find that an accident of construction allows us to observe these effects better than the most carefully arranged instruments. However, every one of these effects can be examined scientifically if we prepare a box so that we can look down into it while shining a double light at its loosely closed lid. As might be expected, the colored shadows described under the physiological colors easily insinuate themselves here.

413. We might recall our earlier discussion concerning the general nature of double shadows, half-lights, and the like; in particular, however, we should experiment with various successive gradations of gray where each step appears light against its dark neighbor and dark against its light one. We can observe this phenomenon quite clearly by using three or more candles at night to produce shadows which progressively cover one another; we will find that the physiological effect described earlier (§38) plays a part here.

414. Only time will tell whether the effects accompanying the appearance of paroptic colors may be derived from the principles of subdued light, semishadows, and the physiological modification of the retina, or whether it will be necessary to resort to certain inner qualities of light as before. Here it is enough to indicate the conditions under which paroptic colors arise, although we also hope that the researcher will not overlook our suggestions of a relationship with effects discussed earlier.

415. Any thoughtful observer will readily make the connection between paroptic colors and dioptric colors of the second class. In both we speak of borders, of light passing across an edge. It is therefore natural that paroptic effects can be enhanced, strengthened, and increased in splendor by dioptric effects. (Here we refer only to instances of objective refraction in which the luminous form actually shines through a medium, for these are in fact related to paroptic colors. The colors of subjective refraction, which result when we view forms through the medium, are quite distinct from paroptic colors, and have already been commended to the reader because of their purity.)

416. The connection between paroptic and catoptric colors is easily surmised from what has been said. Catoptric colors appear only where there are scratches, points, steel strings, or fine threads, which is ap-

proximately the same as light passing across an edge. The light must always shine off an edge if we are to perceive color. As indicated above, this also requires that the luminous form be defined and the light subdued.

417. We will discuss subjective paroptic colors only briefly because they are partly connected with physiological colors and partly with dioptric colors of the second class. For the most part they do not seem to belong here at all, although considered carefully they shed a welcome light on all our principles and their relationship.

418. If we hold a ruler to our eye and look at a candle flame across it, the ruler will seem notched and jagged where the light protrudes. This is apparently the result of the expansive power of light as it affects the retina.

419. The same phenomenon on a larger scale can be seen at sunrise when the sun is clearly visible but has not risen far enough to be unbearably bright. It will then make a sharp indentation in the horizon.

420. When the sky is gray let the observer find a window where the dark intersection of the crossbars stands in contrast to the sky. If he fixes his eyes on the horizontal wooden bar, then tilts his head forward and begins to squint up at it, he will soon see a beautiful yellow-red fringe at the bottom of the bar and a fine light blue one above the bar. The effect will seem all the more vivid when the gray of the sky is darker and more uniform, or when the room is dimmer and thus the eyes more rested. However the attentive observer will be able to see it even on a bright day.

421. By tilting his head back and squinting down at the horizontal bar he can reverse the phenomenon; i.e., the upper edge will appear yellow and the lower one blue.

422. These observations are best made in a dark room. If a white sheet of paper is used to cover the aperture where the solar microscope is usually mounted, the lower border of the disk will appear blue, the upper one yellow, even when the eyes are wide open or narrowed just enough to eliminate the halo around the white. With the head tilted back the colors will appear in reverse.

423. This phenomenon seems to result from the fact that the humors in the eye are truly achromatic only in the center, where we see. At the periphery or when the head is in an unusual position (e.g., tilted forward or backward) it actually retains a chromatic quality, especially when we view sharply contrasting forms. Thus these phenomena may be numbered among those related to dioptric colors of the second class.

424. Similar colors appear when we look at black and white forms through a pinhole in a card. Instead of the white form we can use the pinhole of light in the tin sheet on the camera obscura we prepared for our experiments on paroptic colors.

425. These colors will also appear when we look through a tube in which the far end has been narrowed or indented in various ways.

426. In my opinion the following phenomena are closely related to paroptic effects. When the point of a needle is held close to the eye a double form will arise in the eye. The effect is particularly striking when looking at a gray sky through the knife blades set up for our paroptic experiments. We will seem to look through a veil. Numerous threads will appear to the eye, actually just the repeated forms of the sharp edge, each modified successively by the one following or parallactically by the one opposite. Thus they will be transformed into the shape of threads.

427. Lastly, it must be noted that looking at a point of light in the window shutter through these blades will produce the same colored streaks and halos on the retina as on the sheet of white paper.

428. And so let us close this chapter for the moment, especially since a friend has offered to conduct another series of exacting experiments on the subject. We hope to include the results of his observations in our later description of the illustrative plates and experimental apparatus.

XXXIII. EPOPTIC COLORS

429. Until now we have been dealing with colors which are strong although they disappear immediately upon removal of the conditions for their production. The colors we will now observe are also considered transitory but will stabilize under certain circumstances so that they will remain even after the conditions necessary for the effect are gone. Thus they will serve as a transition from the physical colors to the chemical colors.

430. These colors arise for various reasons on the surface of a colorless object, directly, without mediation, dye, or immersion (βαφή). From their subtlest effect to their most stubborn persistence we will pursue the various conditions necessary for their production. To aid in gaining an overview we will first provide a summary of these conditions.

431. First condition: contact between two flat surfaces of solid transparent objects.

First case: when pieces of glass, plates of glass, or lenses are brought together.

Second case: when there is a crack in a solid piece of glass, crystal, or ice.

Third case: when the lamellae of transparent minerals split apart.

Second condition: when we breathe upon a glass surface or polished stone.

Third condition: a combination of the two conditions above; i.e., when we breathe on the glass plate, lay another glass plate on top of it, and produce colors by pressure. If we slide the second glass plate off, the colors will follow it and disappear with the breath.

Fourth condition: bubbles of various liquids (soap, chocolate, beer, wine), fine glass bubbles.

Fifth condition: very fine films and layers of mineral and metallic solutions; lime film, the surface of standing water (particularly when it contains iron), also oil films on water (especially a film of varnish on aquafortis).

Sixth condition: when metals are heated, the discoloration of steel and other metals.

Seventh condition: when a glass surface begins to decompose.

432. *First condition,* first case. Concentric colored circles will arise at the point of contact between two convex glasses, or convex and plane glass, or best of all, convex and concave glass. The phenomenon will appear with the slightest pressure, and may be carried step by step through various stages. We will begin with a description of the effect at its fullest; such a review of the different stages will give us a clearer insight into the phenomenon.

433. The center will be colorless. The point where the pieces of glass appear to join under the strongest pressure will be dark gray with a silver-white space around it. Various isolated rings will follow at decreasing intervals, every ring consisting of three contiguous colors. Each of the rings (three or four in number) will be yellow on the inside, purple in the middle, and blue on the outside. Between two rings there will be a silver-white interval. The outermost rings are always closer together and alternate between purple and green without a noticeable silver-white space between them.

434. We will now begin with the lightest pressure and observe the phenomenon as it appears by stages.

435. Under the lightest pressure the center itself will appear to have a green color. Next, purple and green rings will extend to the periphery of the concentric circles. They will be relatively wide without any trace of silver-white space between them. The green center is created where the blue of an undeveloped ring merges with the yellow of the first ring. Under this light pressure the other circles are wide enough to merge their yellow and blue borders in a beautiful green. The purple in each ring, however, will remain pure and untouched; thus every ring appears in these two colors.

436. Somewhat stronger pressure will separate the first ring slightly from the undeveloped one, isolating it so that it emerges fully. The

center will appear as a blue spot since there is now a silver-white space between it and the yellow of the first ring. From the blue spot the center will further develop a purple color which will always have an outer border of blue. The second and third rings from the center are now fully isolated. An explanation for any deviations in this will be found in our earlier discussion or the one to follow.

437. Under heavier pressure the center will become yellow with a purple and blue border around it. Ultimately this yellow will also move away from the center; the innermost ring is formed with the yellow color as its border. Now the entire center will appear silver-white, until finally, under the heaviest pressure, the dark spot appears and the phenomenon described at the beginning is fully in place.

438. The size of the concentric rings and the distance between them depends on the shape of the glass being pressed together.

439. We noted above that the colored center consists of an undeveloped ring. The lightest pressure, however, will often reveal that the center contains several undeveloped rings in seminal form, so to speak. These may be developed gradually under the observer's eyes.

440. The regularity of these rings is the result of the convex shape of the glass; the diameter of the phenomenon depends on the size of the spherical section created by the grinding of the lens. It follows that flat pieces of glass pressed together will produce only irregular effects which undulate like watered silk and extend in all directions from the point of pressure. For this reason, however, the phenomenon will seem all the more splendid, and strike every observer with its charm. When the experiment is done as indicated the effects will be the same as those in our earlier experiment: green and purple waves will appear under light pressure, while heavier pressure will isolate streaks consisting of blue, purple, and yellow. In the first case the edges will touch, and in the second they will be separated by a silver-white space.

441. Before discussing this phenomenon further we will describe the most convenient way to produce it.

Place a large convex lens on a table facing a window, and lay a sheet of well-polished mirror glass about the size of a playing card on top of it. The weight of the glass alone will exert enough pressure to produce one or another of the above phenomena. We may produce each stage in sequence by using glass sheets of different weights or other modifications, such as sliding the glass sheet down the side of the convex lens to a point where it does not exert as strong a pressure.

442. To see the phenomenon we must look obliquely at the surface where it appears. In bending down to view it from a sharper angle we will note not only a widening of the rings but also the development of additional rings out of the center. We will find no trace of these ad-

ditional rings if we look at the surface perpendicularly through even the strongest magnifying glass.

443. If the phenomenon is to appear in its greatest beauty we must be careful to have the glass as clean as possible. Leather gloves should be worn when using mirror glass. It is best to clean the inner surfaces before the experiment since the contact between them must be complete; the outer surfaces should be kept clean as we apply pressure to them.

444. It will be evident from the above that full contact is required between two smooth surfaces. Polished glass serves best here. Plates of glass show the most beautiful colors when they fit tightly together; thus the phenomenon should become even more beautiful if we put the plates of glass under an air pump and expel the air.

445. The colored rings appear most beautifully when we bring together convex and concave glass having the same spherical section. Never have I seen the phenomenon more brilliantly displayed than in the lens of an achromatic telescope where the crown glass was apparently fitted too tightly to the flint glass.

446. A curious effect occurs when dissimilar surfaces are pressed together (e.g., a polished crystal and a plate of glass). The phenomenon does not appear in large undulating waves (as in the union of glass with glass); it is small, jagged, and seemingly discontinuous. The surface of the polished crystal (which consists of infinitely small cross sections of lamellae) apparently does not touch the glass as continuously as another piece of glass would.

447. The color will disappear under pressure strong enough to bond the two surfaces so closely that they become as one. Thus the dark spot in the center is created: the lens under pressure no longer reflects light at this point. The same spot will be utterly bright and transparent when held to the light. When the pressure is relaxed the colors will gradually vanish; they will disappear completely when the surfaces are slid apart.

448. This effect will also be found in two cases which are similar. When a single transparent mass separates so that the surfaces of its parts are left in sufficient contact, we will see the same sort of rings and waves. A good way to produce these is to plunge a lump of hot glass into water; the different fissures and cracks will enable us to observe the colors in a variety of forms. Nature often displays the same phenomenon in flawed quartz crystals.

449. In the mineral world, however, we frequently find this effect in rocks which are naturally foliated. The original lamellae are so tightly bonded that rocks of this type can seem fully transparent and colorless. But the internal layers may accidentally separate without losing contact, and thus the familiar effect will often appear, especially in calcareous

spars, selenite, adularia, and other minerals similar in structure. It demonstrates an ignorance of what produces this common accident of nature to consider it so important in mineralogy and attach special value to specimens displaying it.

450. We have yet to mention an extremely curious reversal of this phenomenon reported by researchers. When viewed by transmitted light rather than reflected light the colors are said to be replaced by their opposites in a manner reminiscent of the physiological complements discussed earlier. In place of blue, yellow is supposed to appear, and vice versa; in place of red, green; etc. This will require more exact experimentation, especially as we still have some doubts on this point.

451. If we were now called upon to offer a general statement about the epoptic colors described above as results of the first condition, and to relate these phenomena to the physical phenomena described earlier, we would proceed as follows.

452. The pieces of glass used in the experiments must be considered transparent to the greatest degree empirically possible. In our opinion, however, the close contact produced by pressure instantly creates turbidity on their surfaces, if only a very slight one. Within this turbidity the colors appear immediately. Each ring contains the entire set of colors, for purple will appear where the two opposites, yellow and blue, meet on the end toward red. Green, on the other hand, will appear where yellow and blue touch (as in the prismatic experiment).

453. As we have so often seen, in the genesis of color the entire series is invariably required. This lies in the nature of every physical phenomenon, in the very concept of a polar opposition through which an elemental unity manifests itself.

454. The appearance of a different color when light is transmitted rather than reflected calls to mind the dioptric colors of the first class which we saw created out of turbidity in the same way. There can be little doubt that turbidity is also present here; when extremely smooth glass plates interlock tightly enough to cling together, a partial union is formed which deprives each surface of some smoothness and transparency. The final proof, however, may be found in the observation that at the center, where the lenses are most tightly pressed together, a full transparency is created and no color appears. Confirmation for all this, however, will have to await completion of our general survey.

455. *Second condition.* After breathing on a glass plate, wiping it with a finger, and immediately breathing on it again, we will see vivid colors floating through one another. As the breath evaporates they will move about and finally disappear. If we repeat this, the colors will be even more vivid and beautiful, and seemingly last longer than they did the first time.

456. Although this phenomenon passes quickly and seems confusing,

I have the impression that the following occurs. Initially all the basic colors appear together with their combinations. If we breathe more strongly we can observe a sequence in the effect. As the evaporating breath contracts toward the middle of the glass, blue may be seen to disappear last.

457. The phenomenon appears readily between the delicate streaks left when a finger is wiped across a clear surface; lacking that, some other slight roughening of the object's surface is required. On some glasses just breath is sufficient to produce color, but others needs to be rubbed with a finger. I have even found instances where one side of a polished mirror glass promptly showed color when breathed upon, although the reverse side did not. To judge by the beveling that remained, the former was originally the front of the mirror and the latter was the back which had been coated with quicksilver.

458. These experiments are best done in the cold because the breath mists the plate more quickly and evenly, and evaporates sooner. In frosty weather we can observe this effect on a larger scale when traveling in a coach where all the windows are closed and quite clean. The passengers' breath will cover the windowpanes with a delicate mist and immediately produce a vivid play of colors. I have been unable to note whether there is a regular succession in the colors, but they are particularly vivid when seen against a dark object. This appearance of color does not last long, for as soon as the mist collects in larger drops or turns to ice the effect is lost.

459. *Third condition.* The experiments with pressure and breath may be combined by breathing on a glass plate and then quickly pressing another down on it. Colors will arise as in two unmisted plates, but with the difference that here and there the moisture will create some interruption in the wave pattern. When the two glass plates are slid apart the breath will seem iridescent as it evaporates.

460. It might be asserted, however, that this combined experiment tells us no more than each experiment individually, for it would seem that the colors created by pressure vanish as the plates are separated, and the breath then evaporates with its own colors.

461. *Fourth condition.* Color effects may be observed in almost all bubbles. The most familiar occurrence is in soap bubbles where the iridescence is easiest to describe, but these effects can also be found with wine, beer, pure spirits, and especially in the froth on chocolate.

462. Earlier we stipulated the need for an infinitely narrow space between two surfaces in contact; we may also consider the film of the soap bubble to be an infinitely thin membrane between two elastic bodies, for the effect actually appears between the air inflating the bubble from inside and the air of the atmosphere.

463. At first the bubble is colorless, but colored streaks like those in marbled paper then begin to appear. Finally they spread over the entire bubble, or rather, are driven around it as we inflate it.

464. The bubble may be made in various ways. It can hang freely if we merely dip a straw into the solution and inflate the bubble formed at its end. Here the formation of the colors will be difficult to observe because the rapid rotation makes it hard to see the effect clearly, and there is a confusion of colors. It can be noted, however, that the colors begin at the straw. We can also blow carefully into the solution itself so that a single bubble is formed. The bubble will remain white if we inflate it only a little, but if the solution is not too watery the perpendicular axis of the bubble will be surrounded by rings lying close to one another and usually alternating between green and purple. Lastly, we can produce a group of bubbles in the solution. Here the colors will arise at the partitions formed where two bubbles are pressed flat against one another.

465. It is almost more convenient to observe the colors in bubbles of chocolate froth than in soap bubbles. Although smaller, they last longer. Their warmth produces and maintains an activity, a movement, which seems necessary for the development, succession, and final arrangement of the phenomenon.

466. If the bubble is small or part of a group, colored streaks like those in marbled paper will move across the surface. We will see all the colors of our chromatic diagram in a confusion of movement, pure colors, intensified colors, mixed colors, all sharp, bright, and beautiful. The phenomenon will continue as long as the bubble remains small.

467. When the bubble is larger or grows isolated as those next to it break, we will soon note that this activity and movement of color has a certain tendency; i.e., at the top of the bubble we will see a small ring with a yellow center arise. The other streaks of color will continue their vermiform movement around it.

468. Before long the ring will expand and flow down the sides. It will remain yellow in the center; below and on the outside it will become purple and then blue. Below this a new ring will arise in the same sequence of colors. If the rings are close enough the colors on their edges will combine to form green.

469. By the time I was able to count three such major rings the center had become colorless; the colorless area grew gradually as the rings continued to flow down, until the bubble finally burst.

470. *Fifth condition.* Fine films may be formed in various ways; in these we will discover a vivid play of colors with all the colors moving through one another, either in the familiar order or more confusedly. Water in which unslaked lime is dissolved will soon be covered with

a colored film. The same occurs on the surface of standing water, especially when the water contains iron. The scaly deposits of tartar in a bottle of wine, especially French red wine, gleam with the most beautiful colors if they are carefully loosened and placed in the light. Drops of oil on water, brandy, and other liquids, produce the same rings and flamelets. The most beautiful experiment, however, is the following. Pour aquafortis, not too strong, into a saucer, and with a brush drop into it some of the varnish used by etchers to protect certain parts of the plate during etching. Amid lively movement a film will appear, spread out in rings, and instantly produce the most vivid appearance of color.

471. *Sixth condition.* When metals are heated a fleeting succession of colors will appear on the surface. We can make these colors last if we wish.

472. At a certain temperature, hot polished steel will be covered with yellow, which will remain if the steel is removed quickly from the coals.

473. As the steel becomes hotter, the yellow seems to turn darker, more intense, and soon changes to purple. This color is difficult to hold, for it quickly passes into bright blue.

474. This beautiful blue may be held by taking the steel quickly from the heat and plunging it into the ashes. This is how blue steel work is manufactured. However, if we leave the steel over the fire it will soon turn light blue and remain so.

475. These colors pass like a breath across the surface of the steel, one seeming to flee before the other, but each color is actually developed in succession out of the preceding one.

476. When a penknife is held in the light, a streak of color will appear diagonally across its blade. The part of the streak which had been in the center of the flame is a light blue changing into blue-red. In the center is purple, with yellow-red and yellow following.

477. This phenomenon may be understood from our previous discussion: toward the handle the blade is heated less than at the tip held in the flame, and thus all the colors usually seen in succession will appear simultaneously. In this way we may have a permanent record of them.

478. Robert Boyle describes this succession of colors as follows: "A florido flavo ad flavum saturum et rubescentem (quem artifices sanguineum vocant) inde ad languidum, postea ad saturiorem cyaneum."[58] This would be quite correct if the words *languidus* and *saturior* were exchanged. We will not take up the question of whether the different colors influence the later degree of tempering. Here we are concerned only with how color indicates the various degrees of heat.

479. When lead is calcined the surface turns grayish at first. Heated further, this grayish powder turns yellow and then orange. Silver also shows color when heated. The flash of silver during refinement should be included here. When metallic glasses melt, colors likewise appear on the surface.

480. *Seventh condition.* When the surface of glass begins to decompose. We have already noted the clouding of glass. The term *clouding* is used when the surface of the glass has decomposed enough to appear turbid.

481. White glass clouds first, as does cast glass; polished glass clouds later, with the bluish type being less likely to cloud and the green least likely to do so.

482. A pane of glass has two sides, one of which is called the mirror side. This side (which faced up in the furnace) is characterized by the presence of roundish elevations. It is smoother than the other side which faced down in the furnace, and upon which we often find scratches. In a window the mirror side usually faces inward because it is less subject to decomposition from the condensation of moisture in the room; thus the glass will cloud less.

483. After the glass has become clouded or turbid, colors will gradually appear. These colors can become quite strong; it might actually be possible to discover a certain succession or other regularity in them.

484. And so we have followed the physical colors from their subtlest effects to the point where temporary color phenomena become lasting in the object. Thus we reach the boundary where chemical colors begin; in fact, we have already crossed it to some degree, and as a result our discussion may proceed more smoothly. Nonetheless, we might end this section with a general statement about its inner coherence by adding the following to what was said above (§§451-454).

485. The coloration of steel (and other similar effects) could easily be explained by the principles of turbid media. Polished steel reflects light strongly. We may conceive of the coloration by heat as a gentle turbidity: at first, light yellow would appear, but with increasing turbidity this color would become denser, more concentrated, redder, until at last it would seem purple-red and ruby red. We might imagine this color intensified to the ultimate degree of darkening as the turbidity continued; this turbidity would now cover a dark background and begin to produce violet, then dark blue, and ultimately, light blue. Thus the series of effects would be completed.

We will not claim this explanation is fully satisfactory. Our intention is merely to indicate the path by which we might find an all-encompassing formulation, the true key to the puzzle.

Part Three
Chemical Colors

486. We use the term chemical colors for colors we can excite in objects, fix to some degree, intensify in objects, or remove again and impart to other objects. We may therefore ascribe a certain immanent quality to them. For the most part they are characterized by permanence.

487. Chemical colors were earlier given various names as a reflection of this. They were called *colores proprii, corporei, materiales, veri, permanentes, fixi*.

488. We began the transition from our previous discussion by noting how the changeable and temporary element of physical colors became more and more permanent in objects.

489. Color becomes fixed in objects with some permanence, either on the surface or throughout.

490. All objects are capable of coloration when we excite it in them, intensify it, gradually fix it, or at least impart it to them.

XXXIV. Chemical Opposition

491. In presenting color phenomena we frequently had reason to call attention to a juxtaposition of opposites; in the area of chemistry we will encounter chemical opposition as an important principle. For our purposes we will mention only those opposites which go under the general names of acid and alkali.

492. We may characterize chromatic opposition with a plus or minus, as is the practice with all other physical opposites. If we assign the plus to the yellow side and the minus to the blue, they will correspond in chemical cases to the chemical opposites. Yellow and yellow-red will involve the acids, blue and blue-red the alkalis. Thus the phenomena of chemical color may be followed in a fairly simple way, although many other things must be taken into account as well.

493. Since the principal phenomena of chemical color occur mostly in the oxidation of metals, this subject will clearly be of importance here at the beginning. In each section we will treat other subjects as they arise, but we must point out now that we intend to offer the chemist only a few preliminary remarks of a general nature without entering into detail or resolving the subtler problems and questions of chemistry. Our only purpose is to provide a sketch of how the principles of chemical color might be connected with the general principles of physical color, at least in our view.

XXXV. SOURCE OF WHITE

494. We have already touched on this subject in our discussion of dioptric colors of the first class (§§145 ff.). Transparent objects are at the highest level of inorganic materiality. Pure turbidity follows, and white may be considered to be the fullest degree of pure turbidity.

495. Pure water seems white when crystallized as snow, for the transparency of the individual parts does not create a transparent whole. Various salt crystals appear as a white powder after the water of crystallization has evaporated. We could use the word "white" to describe purely transparent objects in an accidental state of opacity; crushed glass, for example, looks like a white powder. Here we might keep in mind that a dynamic connection has been eliminated and the atomistic character of the material revealed.

496. In their pure state all the known irreducible earths[59] are white. Through natural processes of crystallization they become transparent; silica turns to quartz, clay to mica, magnesia to talc, calcareous earth and barite appear in many spars.

497. Since metallic oxides are the chief source of color in minerals, we will end by noting that the beginning stages of mild oxidation produces white oxides; lead, for example, is changed into white lead by acetic acid.

XXXVI. SOURCE OF BLACK

498. Black seems to arise at a less elementary level than white. In the vegetable kingdom we meet it in partial combustion: a black color appears in charcoal (a remarkable object in other respects as well). When wood (a board, for example) is deprived of some combustible content by light, air and moisture, a gray color will appear first, and then black. We can likewise make animal parts into charcoal through partial combustion.

499. In metals, too, we often find a black color created when there is partial oxidation. Thus many metals turn black with mild oxidation (through vinegar or weak acid fermentations like a decoction of rice). This is especially true of iron.

500. Again, we may infer that a reduction or deoxygenation produces the color black. This is the case in the manufacture of ink where iron turns yellow when dissolved in strong sulfuric acid but appears black when partially deoxidized by the addition of an infusion of gallnut.

XXXVII. EXCITATION OF COLOR

501. In our consideration of turbid media in the previous section on physical colors we saw colors first, then white and black. Now we will

assume the presence of a fixed white and black, and ask how color can be excited in them.

502. Here, too, we can say that a darkened or turbid white turns yellow, a brightened black turns blue.

503. Yellow arises on the active side, next to light, brightness, white. Anything with a white surface yellows easily—paper, linen, cotton, silk, wax. Clear combustible liquids are especially prone to yellowing, i.e., they easily become slightly turbid.

504. Excitation on the passive side next to dark, darkness, black, always brings the prompt appearance of blue, or rather, reddish blue. If a glass containing iron dissolved in sulfuric acid and highly diluted with water is held to the light, and a few drops of an infusion of gallnut are added, it will produce a beautiful violet color which shows the qualities of smoky topaz, the *orphninon*[60] of a burnt purple as the ancients called it.

505. Can natural or artificial chemical processes excite color in the pure earths without the addition of metallic oxides? This important question is usually answered in the negative. It is perhaps connected with the question of whether oxidation can produce a change in the earths.

506. The negation of the question is supported by the fact that a trace of metal, especially iron, appears wherever mineral colors are found. Here, of course, we must consider how easily iron oxidizes, how easily iron oxide takes on different colors, how finely divisible it is, and how quickly it imparts its color. It would be desirable, however, to conduct new experiments on this point and either confirm or remove the doubt.

507. Nonetheless, the earths are extremely receptive to colors which are already present; this is especially true of alum earth.

508. We now come to the metals which have almost exclusive rights to the appearance of color in the inorganic kingdom; we will find they differ from the pure earths in their tendency to show some color even in their pure, separate, reguline state.

509. Silver is closest to pure white; in fact, it actually represents pure white heightened by a metallic sheen. Steel, tin, lead, etc., tend to pale blue-gray, but gold rises to pure yellow and copper comes close to red, intensifying almost to purple under certain circumstances, but returning to a yellow-gold color when the copper is combined with zinc.

510. In their pure state, metals show these specific proclivities for one color characteristic or another, but the effects of oxidation reduce them to a somewhat common set of characteristics. For the basic colors now appear in their full purity; regardless of the affinity metals might have for a certain color, we know that some can produce the entire circle of colors and others can show more than one color (tin is an exception because of its resistance to coloration). In the future we will

provide a table which shows the degree to which various metals can produce the different colors.

511. The smooth, clean surface of a pure metal will be covered with a breath of color when heated, and produce a series of effects as the heat intensifies; we think this indicates the ability of metals to traverse the entire circle of colors. This phenomenon appears most beautifully in polished steel, but silver, copper, brass, lead and tin readily show similar effects. Apparently oxidation of the surface plays a role here, as we can prove by continuing the process, especially with the more easily oxidized metals.

512. This view is apparently supported by the fact that red-hot iron oxidizes more quickly in acid solutions; one effect reinforces the other. We will also note that steel is said to show variations in elasticity which depend on the stage of coloration reached in its hardening. This is natural, since the different colors indicate the various degrees of heat.

513. In going beyond this superficial breath, this film, to observe how a metal is oxidized throughout its mass, we will find white or black at the first stage; this can be seen in white lead, iron, and quicksilver.

514. If we now investigate the actual excitation of color, we will find it occurs most frequently on the plus side. The often-cited discoloration of smooth metal surfaces begins with yellow. Iron turns quickly to yellow ocher, lead from white lead to massicot, quicksilver from ethiops to yellow turpeth.[61] Solutions of gold and platinum in acid are yellow.

515. Excitations on the minus side are less frequent. Slightly oxidized copper appears blue. Alkalis play a role in the preparation of Prussian blue.

516. In general, however, these color effects are so uncertain that chemists themselves view them as unreliable indicators when taken in fine detail. For our purposes we can only deal with this material in broad outline, but we will note that it might someday be possible to arrange the metallic color effects, at least for didactic use, according to how they appear and vanish with oxidation, peroxidation, reduction and final deoxygenation.

XXXVIII. INTENSIFICATION

517. Intensification appears as a condensation, saturation, darkening of color. In our earlier discussion of colorless media we saw that an increase in turbidity could intensify a luminous object from light yellow to the deepest ruby red. Conversely, blue intensifies to the most beautiful violet when we rarefy and diminish a light-filled turbidity placed in front of darkness (§§150, 151).

518. The same thing happens with specific colors. Supposing we have two vessels of white porcelain made with stepped bottoms. If we fill

one with a clear yellow liquid, the fluid will seem redder with each step down and finally appear orange. If we pour a clear blue solution into the other vessel, the top step will show a sky blue, the bottom of the vessel a beautiful violet. If we put the vessel in the sun, the shadow side of the top step will also be violet. A shadow cast by our hand or some other object over the illuminated part of the vessel will likewise seem reddish.

519. This is one of the most important phenomena pertaining to the principles of color; it is evident that a quantitative relationship produces a qualitative impression on our senses. Here we will recall our earlier conjecture, made in connection with the last class of epoptic colors (§485), that the discoloration of steel might be explained through the principles of turbid media.

520. Every chemical intensification is the immediate consequence of excitation. It proceeds continuously, steadily, and we should note that intensification most often occurs on the plus side. Yellow iron ocher is intensified by fire or other processes to a very deep red. Massicot is intensified in minium, turpeth in vermilion; the latter has already reached a very high degree of yellow-red. Here the metal is thoroughly permeated by acid and separated into parts which are empirically infinite in number.

521. Intensification on the minus side is less frequent, although we must note that the purer and more concentrated the preparation of Prussian blue or cobalt glass, the more it takes on a reddish sheen and becomes like violet.

522. The French have a fine expression for this subtle intensification of yellow and blue toward red; they say the color has an *œil de rouge*, which we might express as a *reddish glint*.

XXXIX. CULMINATION

523. Culmination occurs when intensification is continued. Its zenith is found in a red containing neither yellow nor blue.

524. A striking example of culmination on the plus side is once again provided in the discoloration of steel as it reaches the purple zenith where it can be held.

525. To use the terminology introduced above (§516) we would say that initial oxidation produces yellow and peroxidation produces yellow-red; here a certain limit is reached, for next comes reduction followed by final deoxygenation.

526. High levels of oxidation produce a purple color. Gold appears purple when precipitated from its solution by a solution of tin. Oxide of arsenic combined with sulfur produces a ruby color.

527. We have yet to investigate the extent to which some type of

reduction plays a role in cases of culmination. The effect of alkalis on yellow-red also seems to create a culmination by forcing the color to the zenith through the minus side.

528. The Dutch prepare a color called vermilion from the best Hungarian cinnabar of the deepest yellow-red. It is still just a cinnabar, but one which approaches a purple color. We would surmise that alkalis are used in an attempt to bring it closer to culmination.

529. We find a notable example in vegetable juices which undergo this process. The dyes in turmeric, annatto, safflower, etc., are extracted by alcohol to produce yellow, yellow-red, and hyacinth-red tinctures. When alkalis are added they rise to the zenith and even go beyond into blue-red.

530. I know of no instance in the mineral and vegetable kingdoms of culmination from the minus side. In the animal kingdom the juice of the purple snail is worthy of note; later we will speak of its intensification and culmination from the minus side.

XL. BALANCING

531. The instability of color is so great that even the pigments we consider fixed can be changed in one way or another. This is most noticeable near the point of culmination, where the alternate use of acids and alkalis may create a striking effect.

532. To express this phenomenon in dyeing the French use the word *virer,* which means to turn from one side to the other. This is an apt way to convey what we otherwise indicate through a certain ratio of components.

533. The use of litmus provides one of the best-known and most striking examples of this. Litmus is a dye which turns red-blue in the presence of alkalis. It readily changes to red-yellow with acids and back to red-blue with alkalis. We will leave it to experts in this art to discover whether there are subtle experiments which might find and fix a culmination point in this process. The art of dyeing (especially with scarlet) offers many examples of this changing back and forth.

XLI. TRAVERSING THE CIRCLE

534. Excitation and intensification occur more on the plus side than the minus side. Thus in traversing the entire circle most colors will begin on the plus side.

535. The discoloration of steel shows a steady and obvious passage from yellow through red to blue.

536. With different degrees and types of oxidation, metals can be fixed at various points of the color circle.

537. Since they may also appear as green, we must ask whether there is any known process in the mineral kingdom which passes continuously from yellow through green to blue and vice versa. Iron oxide smelted with glass produces green at first, and then blue when heated further.

538. This is perhaps the place to speak of green in general. It is most likely to occur on an atomistic level, and appears with complete purity when we put yellow and blue together. Even an impure dirty yellow gives us the impression of being greenish. Yellow and black make green, but this is a result of the fact that black and blue are related. An imperfect yellow like sulfur-yellow strikes us as greenish. We will also see an imperfect blue as green. The green in wine bottles apparently comes from an imperfect union of iron oxide and glass. Increased heat and a more complete union will create beautiful blue glass.

539. All these things seem to indicate a certain gap between yellow and blue in nature. Intermixture and blending can bridge this gap on an atomistic level and join the colors in green, but the real connection between yellow and blue is made through red.

540. We will find that what seems unsuited to the inorganic kingdom can occur when we come to organic beings, for the organic kingdom offers real examples of such a passage through the circle from yellow through green to blue, and then to purple.

XLII. Reversal

541. A direct reversal of the color to the complementary opposite may also occur. We can say only the following about this remarkable phenomenon.

542. The mineral chameleon[62] (which actually contains manganese oxide) appears as a green powder when completely dry. Added to water, it dissolves with a beautiful green color but then changes quickly to purple, the color opposite green. No intermediate stage is discernible.

543. The same is true of sympathetic ink; it appears reddish as a fluid but looks green on paper after being warmed and dried.

544. The true source of this phenomenon seems to be the conflict between dryness and moisture, a fact already observed, if we are not mistaken, by analytic chemists. Only time will tell what else can be found to help us understand these phenomena.

XLIII. Fixation

545. Until now we have found color unstable even when it appears in objects. Nonetheless, it can be fixed under certain circumstances.

546. Some substances can be changed entirely into dye, and here we may say the color is fixed within itself, stops at a certain point, and

becomes specific. Thus materials for dye come from every kingdom of nature; the vegetable kingdom offers a particularly rich source. A few of these are especially notable and may be considered representative of the others; e.g., madder on the active side, indigo on the passive side.

547. To make these materials useful we must concentrate the coloring agent in them, and refine the dye to a state of almost total divisibility. This can be done in various ways; with the above materials in particular it is done through fermentation and decomposition.

548. These dye substances may then be fixed in other objects. In the mineral kingdom they seize upon earths and metallic oxides; they unite with glass in melting and are clothed in great beauty when light shines through them. Here they can be considered to last forever.

549. They fasten on vegetable and animal bodies with varying degrees of power, and a permanence which depends partly on their nature (e.g., yellow is less permanent than blue), and partly on the nature of the object. In vegetable substances they are less permanent than in animal ones, and even within each kingdom there are further differences. Linen or cotton thread, silk or wool will each have a different relationship to dyes.

550. Here we encounter the important principle of mordants which can be considered mediators between the color and the object. Manuals on dyeing describe these in detail. For our purposes it will suffice to indicate that this process gives the color a permanence which will last the lifetime of the object and may even increase the clarity and beauty of the color.

XLIV. MIXTURE, REAL

551. Every mixture presupposes a specific state, and thus in speaking of mixtures we are on an atomistic level. We need certain substances already fixed at some point on the circle of colors before we can mix them to produce new shades.

552. In general we may assume the existence of yellow, blue, and red as pure and basic colors. Red and blue will produce violet; red and yellow, orange; yellow and blue, green.

553. Much effort has been expended on finding ratios of number, measure, and weight to define these mixtures more clearly, but little has come of this.

554. The art of painting is really based on the mixture of such specific—even individualized—color substances, and on the infinite possibilities they offer for combination. Only the most subtle and practiced eye can have a feeling for these combinations and exercise the judgment needed to apply them.

555. Grinding, washing, etc., will join these mixtures thoroughly in a perfect dispersion, as will fluids like oils, resins, etc., which hold the powdered material together and act organically, as it were, to combine inorganic substances.

556. All the colors mixed together retain their general character as σκιερόν.[63] Since we no longer see them in sequence we will experience no totality, no harmony; a gray will appear which resembles visible color in seeming somewhat darker than white and somewhat lighter than black.

557. This gray may be produced in various ways. First, by mixing yellow and blue to an emerald green and then adding pure red until the three colors neutralize one another. Second, a gray will also arise if the primary and derivative colors are arranged in a sequence of certain proportions and then mixed together.

558. The idea that a mixture of all the colors makes white is absurd, yet despite the evidence people have been credulous enough for the last hundred years to echo it along with other absurdities.

559. Colors mixed together will carry their darkness into the mixture. As the colors are darker the gray they create will be darker, until it finally approaches black. As the colors are lighter the gray will become lighter, finally approaching white.

XLV. MIXTURE, APPARENT

560. Apparent mixture also deserves notice here for it is important in many ways. The mixture described above as real might also be considered apparent; the elements from which the compound color arises are merely too small to be seen individually. Yellow and blue powder rubbed together look green to the naked eye, but we can still distinguish yellow and blue through a magnifying glass. In the same way, yellow and blue streaks will make a green surface at a distance; similar effects will be created in the mixture of any other fixed colors.

561. In our planned discussion of materials we will describe a flywheel upon which an apparent mixture is produced by rapid motion. The various colors are arranged in a circle on a disk and spun rapidly on the flywheel; by making several disks we can create every mixture possible in nature, including the mixture of all colors into gray.

562. Physiological colors may also be mixed. For example, the blue shadow (§65) cast on a light yellow paper will look green. The same will be true of the other colors we know how to create.

563. A lingering afterimage in color (§§39 ff.) seen against a colored surface will create a mixture leading to a new color in the image, a color derived from both sources.

564. Physical colors also exhibit mixture. Here we might mention

the experiments where we looked at multicolored forms through a prism (described in detail above, §§258-284).

565. However, physicists have been most interested in the effects created when prismatic colors fall on colored surfaces.

566. What we see here is quite simple. To begin with we should recall that the prismatic colors are much more vivid than the colors of the surface upon which they fall; we must then consider that the prismatic color may be either homogeneous or heterogeneous with the surface. In the first case the color will heighten and beautify the surface, and be beautified by it like a colored jewel on a foil of similar color. In the second case the one will dirty, disturb, and destroy the other.

567. These experiments can also be done by letting the sun shine through colored glass onto colored surfaces. The results will be similar.

568. The same effect will be found when the observer looks at colored objects through colored glass; the colors of the objects will be heightened, degraded or canceled accordingly.

569. Prismatic colors projected through colored glass will create fully analogous effects; the degree of energy, the amount of light and darkness, and the purity and clarity of the glass will all play a part in bringing forth a variety of subtle differences. These may be observed by anyone with the interest and patience to study these phenomena.

570. It is hardly necessary to add that several pieces of colored glass or oiled translucent paper put together will allow the experimenter to produce and view any kind of mixture at will.

571. Lastly, the use of glazes in painting deserves mention. The mixture these create has a much more spiritual quality than the mechanically atomistic mixtures normally used.

XLVI. TRANSMITTAL, REAL

572. Once colored substances are manufactured in the way indicated, we face the question of how their color can be transmitted to colorless objects. The answer to this question will be of great importance in daily life, in usage, in practical application and technology.

573. Here we must again consider the quality of darkness in each color. From yellow, close to white, through orange and minium to pure red and carmine, through all the gradations of violet down to the deepest blue just next to black, the color continually increases in darkness. Once fixed, blue can be thinned, brightened, or combined with yellow and shifted toward the side of light to produce green. None of these things, however, are in keeping with its nature.

574. In physiological colors we have already seen that colors are a subtraction from light; they arise as the impression of light fades, and even leave the impression of darkness at the end. In physical experi-

ments the use of turbid media and the effect of turbid auxiliary forms will show us that a subdued light, a transition to darkness, is involved.

575. The first phase in the chemical creation of pigments gives evidence of this principle. The yellow breath spreading across steel darkens the gleaming surface. In the transformation of white lead to massicot the yellow is clearly darker than the white.

576. This process is extremely delicate, and so is intensification as it grows and colors the treated object ever more thoroughly and powerfully. Thus the particles involved show their extreme fineness, their infinite divisibility.

577. With the colors which tend toward darkness, and thus with blue in particular, we can arrive at a full black. As an example, a very perfect Prussian blue (indigo treated with sulfuric acid) will appear almost black.

578. Here we must note a strange effect. Pigments in their most saturated and concentrated state no longer show their color, for a decidedly metallic sheen tinged with the physiological complementary appears on their surface. This is especially true of vegetable pigments like the indigo mentioned above, or very intense madder.

579. Any good indigo will show a copper color when broken, a characteristic helpful in commercial manufacture. Indigo treated with sulfuric acid shows a color close to orange when applied thickly or dried so that neither the white paper nor the porcelain saucer can be seen.

580. Bright red Spanish rouge, apparently prepared from madder, shows a perfect green metallic sheen on its surface. When either color, blue or red, is brushed out on the porcelain or paper, it will return to its natural state, for the brightness of the background can shine through.

581. Colored liquids look black when no light passes through them; this is readily shown in a cubical tin container with a glass bottom. On a black surface any clear, colored liquid in the container will look black and colorless.

582. If we arrange a flame so that it is reflected from the bottom, the image will appear colored. When the container is held above a piece of white paper the light shining through it will produce the color of the liquid on the paper. Any light background seen through such a colored medium will show the color of the medium.

583. Any color must contain a veiled light if it is to be seen; thus the brighter and shinier the background, the more beautiful the color. If we paint colored lacquer over a bright, white, metallic background (as in the manufacture of our so-called foils), the color created by the reflected light will have a brilliance equal that of any in our prismatic experiments. Indeed, the energy of physical colors derives primarily from the light constantly at work within them and behind them.

584. Lichtenberg, who of course followed the traditional concepts of his time and place, was nonetheless too good an observer and too

intelligent not to see what took place in front of his eyes and then seek to explain and classify it as best he could. In his preface to Delaval he says:

> For other reasons, too, it seems . . . probable to me that if our organ of sight is to experience color it must at the same time experience something which is all light (white).[64]

585. The main concern of the dyer is to establish white backgrounds for his work. Any fixed color may readily be transmitted to colorless earths, especially alum. However, the dyer must work mostly with animal and plant products.

586. Everything living seeks color, individuality, specificity, effect, opacity even in its most finely divided parts. Everything which has died tends to white, abstraction, generality, clarity, transparency.

587. The technical means for doing this will be indicated in the section on the removal of color. Here in connection with transmittal we must consider that living animals and plants produce their own color, and thus after their color is removed completely they will be all the more ready to accept a new color.

XLVII. TRANSMITTAL, APPARENT

588. It is easy to see the correspondence between transmittal and mixture, both true and apparent. Thus we will not repeat what has been described already in enough detail.

589. For the present, however, we will note more fully the importance of an apparent transmittal produced by reflection. Well known yet significant, this phenomenon is of great importance to the physicist as well as the painter.

590. Let us place a surface of any fixed color in the sun and let the light reflected from it fall on other colorless objects. This reflected light is a type of subdued light, a semilight, a semishadow which mirrors the specific color of the surface along with its own subdued quality.

591. On a light surface this reflected light will be lost and its color scarcely seen. In dark areas, however, an almost magical union with the σκιερόν will appear. Shadow is the true element of color, and in this instance it is lit up, colored, and enlivened by the addition of a shadowed color. And thus there arises a phenomenon as powerful as it is pleasing, one which can be of great service to the painter who knows how to use it. This is the model for the so-called reflexes noticed only late in the history of art and too seldom used in their full variety.

592. The Scholastics called these colors *colores notionales* and *intentionales*. In fact, history will show that this school made care-

ful enough note of these phenomena and knew how to differentiate them, although their approach to such subjects differed greatly from ours.

XLVIII. REMOVAL

593. There are many ways to remove color from objects regardless of whether the color was natural or transmitted. We can remove the color from them as desired, although color also has a way of vanishing against our wishes.

594. The elemental earths are naturally white, but it is also possible to whiten vegetable and animal materials without destroying their structure. For many uses a pure white is desirable and necessary; we prefer to use uncolored linen and cotton goods, and the whiter the silk, paper, etc., the more pleasing we find it. We have also observed that the basis of all dyeing is a white background. Thus, partly by accident and partly through research, technology has pursued the removal of color from these materials avidly; numerous experiments have been done and many important discoveries made.

595. Complete removal of color is the main concern of the art of bleaching which several authors have dealt with from the standpoint of method or practice. Here we will indicate just the main points.

596. Light is considered one of the principal means of removing color from objects, mere weak daylight as well as sunlight. Both types of light, sunlight and indirect daylight, can ignite Bologna phosphorus,[65] and both can also affect colored surfaces. Perhaps light attacks color which is related to it—ignites it, as it were, and burns the color which has so much of flame in it, thus dissolving the fixed element into a general one again. It may also be that some other unknown process takes place. In any case, light has great power over colored surfaces and will bleach them to some extent. Here, too, the various colors show different degrees of perishability and permanence; yellow, especially when prepared from certain materials, will be the first to vanish.

597. Not only light, but air, and especially water, are powerful agents in the removal of color. It is even said that well-dampened thread spread on the grass at night will bleach better than equally damp thread exposed to sunlight. Thus water again appears as a solvent, a mediating agent which eliminates extrinsic qualities and returns the particular to the general.

598. Removal may also be accomplished with reagents. Alcohol has a special tendency to attract the coloring agent in plants and take on the color itself, often in a very permanent way. Sulfuric acid is very effective in removing color, especially from wool and silk, and everyone

is familiar with the use of sulfur fumes to restore a yellowed or spotted white.

599. The strongest acids are the most efficient bleaching agents according to modern practice.

600. The alkaline reagents are also effective but work in an opposite way: lye itself, the oils and fats combined with lye in soap, etc. Descriptions of such things may be found in books on the topic.

601. It might well be worth the trouble to conduct certain delicate experiments on the action of light and air in removing color. Dyes of a known permanence could be exposed to light under a bell jar in which there is a vacuum, common air, or a special gas. We could then see if some of the volatilized color is deposited on the glass or in some other form, and whether this reappearance of color is exactly like the color which has vanished, or is changed in some way. Skilled experimenters should be able to find a variety of means to set up such experiments.

602. Having considered natural effects which work to our advantage, we must now speak of those which work against us.

603. In the art of painting we often see the most beautiful products of the spirit and hard work destroyed in various ways by time. Thus every effort is made to find permanent pigments and bind them to one another and their ground so that their permanence is further insured. The techniques used in schools of painting offer a good demonstration of this.

604. Here we must also mention a minor art to which we owe much in connection with dyeing, i.e., tapestry weaving. In imitating the subtle shadings of a painting it was often necessary to bring together a large variety of dyed materials, and it soon became clear that the colors were not of equal durability, that some faded from the woven picture earlier than others. Thus an intense effort was made to insure the same durability in all the dyes and shades. This was a particular interest of the French under Colbert, whose regulations in this area marked a turning point in the history of dyeing.[66] So-called *bon teint* was pursued by a special guild and promised only a short-lived charm. Others sought all the more earnestly to establish a technique leading to permanence.

In considering the removal, perishability, and impermanence of brilliant color phenomena we have now returned to the need for permanence, and thus we have come full circle in this subject.

XLIX. TERMINOLOGY

605. With what we have learned about the origin, development, and relationship of colors it will be easier to judge where a new terminology would be desirable and where the old should be retained.

606. Like all terminologies, especially those applied to objects of the

sense world, color terminology has proceeded from the specific to the general and returned again from the general to the specific. The name of the species was used for the generic name under which the individual was then categorized.

607. This approach was made possible by the flexibility and inexact nature of language in earlier times, especially since people could rely on a more lively sensory perception in those days. The qualities of objects were described inexactly because everyone had a clear hold on them in imagination.

608. The circle of pure colors was limited, but in numerous objects it appeared as specific, individualized, and defined with secondary characteristics. If we look at the richness of expression in Greek and Latin we will note with pleasure how flexibly and reliably the words can be applied through almost the entire circle of colors.

609. In later times new shadings arose through the various processes of dyeing. The colors of fashion alone, and their designations, represented a vast array of color differentiations. From time to time we also employ the color terminology of modern languages; here we always find an attempt to provide more precise definitions, to grasp and isolate a fixed and specific quality through language.

610. German terminology has the advantage of possessing four concise names which carry no reminder of their origin: yellow, blue, red, green.[67] Without a hint of anything specific these convey only the most general quality of color to our power of imagination.

611. Between each of these four we might insert two further designations: red-yellow and yellow-red, red-blue and blue-red, yellow-green and green-yellow, blue-green and green-blue. These would provide enough definition to express the shadings in the circle of colors. We could add the designations for light and dark and some reference to muddied shades with the monosyllabic words black, white, gray and brown. This approach should serve well enough to express the actual phenomena without raising the question of whether they come about atomistically or dynamistically.

612. Here specific and individual expressions might also be useful; we have used the words orange and violet. Similarly, we have used the word purple for the pure red in the central position because the juice of the purple snail, especially in a fine linen, can be brought to the highest point of culmination by sunlight.

L. MINERALS

613. The colors of minerals are entirely chemical in nature, and thus their origin may be deduced in large part from what has been said about chemical colors.

614. Color is the principal external characteristic in the description of minerals. In keeping with the modern age, great pains have been taken to define and fix every phenomenon exactly, although it seems to us that this approach has only created new difficulties and proven inconvenient in practice.

615. This is, of course, understandable when we recall how it came to be. It has always been the painter's prerogative to work with color. The few fixed colors were well defined, but artificial mixtures were used to create various shadings which imitated the surfaces of objects in nature. No wonder, then, that people turned to this way of mixing, and called upon artists to provide colored samples as guides to judging and characterizing natural objects. For them it was not a matter of how nature works to produce this or that color in its inward, living way, but of how the painter enlivens dead objects to create an illusion resembling the living object. Thus they always began with mixture and returned to mixture, attempting in the end to combine the mixtures to express or distinguish some unique and individual peculiarity in color.

616. We must add something more about the terms for color used in mineralogy. The names were taken from all sorts of visible objects, not from the mineral kingdom as might have been possible in most cases. It would have been advantageous to remain within the same realm. Furthermore, too many individual, specific expressions were adopted; in trying to form new definitions by combining these specific terms people overlooked the fact that they thereby obliterated any image for their imagination and any concept for their reason. Lastly, even these color terms, used to some extent as basic definitions, are poorly organized; this is true, for example, in regard to their derivation from one another, for the student must learn each term individually by memorizing something dead and dogmatic. This is not the place to continue discussing what is touched on here.

LI. PLANTS

617. The colors of organic objects in general may be considered a higher level of chemical process, spoken of by the ancients as "coction" (πέψιζ). All the basic colors as well as their mixtures and derivatives occur on the surfaces of organic beings, but the interiors, although not uncolored, seem poorly colored when opened up. We will give our views on organic nature elsewhere; the present discussion will concern only what is related to the principles of color, and serve as an introduction to those later views. Let us begin with a discussion of plants.

618. Seeds, bulbs, roots, and anything else hidden from the light or directly surrounded by soil will appear white.

619. Plants grown from seed in the dark are white or yellowish. In acting on a plant's color, however, light also affects its form.

620. Plants grown in darkness continue shooting up from node to node, but between each pair of nodes the stem is longer than it should be. No side twigs are produced, and the metamorphosis of the plant never takes place.

621. Light, on the other hand, puts the plant into an active state; it appears green, and the process of metamorphosis continues without interruption until reproduction occurs.

622. We know that the stem leaves merely precede and announce the instruments for flowering and fruiting; thus we may find colors present in the stem leaves which bear a distant resemblance to those in the flower (as is true of the amaranths).

623. There are white flowers in which the petals have achieved the highest degree of purity, and colored ones in which this beautiful elementary phenomenon may be seen here and there. There are also those which have only partially freed themselves from green to reach a higher level.

624. Flowers within one genus, or even one species, may have a variety of colors. For example, roses, and mallows especially, will traverse a great portion of the color circle, from white to yellow, then through red-yellow to purple, and from there to the darkest shade attainable by purple as it approaches blue.

625. Other flowers already start at a higher stage, like the poppy which begins with yellow-red and approaches violet.

626. There are also colors which are predominant but not uniform throughout species, genera, even families and classes. This is especially true of yellow, while blue is generally rarer.

627. A similar process occurs when the juicy capsules of the fruit turn from green through yellowish and yellow to the deepest red, the color of the rind serving to indicate the stages of ripening. Some are colored all around, and some only on the sunny side; in the latter case it is easy to see how the yellow intensifies to red as the colors push toward and over one another.

628. Many fruits are also colored on the inside; purple-red juices are especially common.

629. Color exists on the surface in the flower and penetrates into the fruit, but it also spreads through the other parts to color the roots and the juices of the stem with a rich and powerful hue.

630. Thus the color of wood runs from yellow through the different stages of red to purple and brown. I know of no blue woods; at this stage of structural development we already find the active side asserting its power, although both sides balance in the general green of plants.

631. We observed above that the seed emerging from the soil appears

white or yellowish for the most part, but turns green through the effect of light and air. Something similar occurs with the young leaves of trees, as we can see in the birch where the new leaves are yellowish and yield a beautiful yellow extract when boiled. Later they turn greener, while the leaves of other trees turn gradually blue-green.

632. The yellow component appears to be a more essential part of the leaves than the blue, for the latter vanishes in the fall when the yellow of the leaf shows a change to brown. Even more remarkable are the cases where the leaves return to pure yellow in the fall; or intensify to the deepest red.

633. It is a characteristic of some plants that artificial treatment will turn them almost completely into a dye as fine, effective, and infinitely divisible as any other. Examples are the indigo and madder which find such frequent use. Lichens are also used in dyeing.

634. Another phenomenon stands in contrast to this: it is possible to extract the coloration of plants and show it separately, as it were, without any change in the structure of the plant. Alcohol will extract the colors of flowers and be tinged by them; the petals will then appear white.

635. Reagents affect flowers and their juices in various ways; Boyle did many experiments on this. Roses are bleached by sulfur and restored by other acids. Tobacco smoke will turn roses green.

LII. WORMS, INSECTS, FISH

636. We will begin with the following observations about animals which have remained at a lower level of structure. Worms living in the soil surrounded by darkness and cold moisture appear poorly colored, while intestinal worms, hatched and nourished in dark, warm moisture, are without color. Light appears to be an express requirement for the production of a particular color.

637. Some degree of color appears in aquatic creatures; although it is a dense medium, water lets sufficient light pass through. The zoophytes, which appear to live in the purest calcareous earth, are mostly white, but we find corals intensified to the most beautiful yellow-red and the casings of other vermiform creatures raised almost to purple.

638. The outer coverings of animals with shells are beautifully marked and colored, but it must be noted that neither land snails nor freshwater shellfish display the deep colors of those in the ocean.

639. In observing the shell of a shellfish, especially a spiral one, we will note that it must have been formed by a set of animal organs similar to one another which moved forward as they grew; in turning around their axis they produced an ever larger casing with a series of chambers,

septa, channels and elevations. But we will also note that these organs must have been accompanied by some colored juice which marked the surface of the shell, apparently under the direct influence of sea water, with colored lines, dots, flecks, and shadings at each stage. Thus the outside of the shell carries permanent traces of the evolution in its growth, while the inside is most frequently white or pale in color.

640. Observation will offer further evidence of such juices in shellfish, for they yield it as a liquid dye. The juice of the cuttlefish is an example, but a better example is the purple juice found in many snails, a juice famed since antiquity and still used today. In the intestines of many vermiform shell-dwellers there is a certain sac filled with a red juice. This contains a strong and lasting dye; it is possible to crush the whole animal, then cook it and extract a good liquid dye from the animal broth. This dye-filled sac can also be removed from the animal to create a more concentrated liquid.

641. When exposed to light and air this juice has the peculiarity of seeming yellowish at first, then greenish; this changes to blue, and from there to violet. The red deepens and finally the effect of the sun turns it a pure bright red, especially in batiste.

642. This would represent an intensification from the minus side, something not readily found in the inorganic realm. In fact, we could almost call this effect a traversal of the entire circle. We are convinced that the right experiments could actually produce a complete traversal, for there is no doubt that properly applied acids would shift it past the point of culmination and toward scarlet.

643. In one respect this liquid seems connected with reproduction; such a dye may even be found in eggs, the beginning stage of shellfish. In another respect this juice seems to hint at the blood developed in higher animals, for blood has similar color properties. In its dilute state it seems yellow; thickened, as in our veins, it appears red. Arterial blood shows a brighter red, apparently because of the oxygenation provided by breathing; venous blood tends to be more violet. In its variability blood points to the familiar principles of intensification and traversal.

644. Before leaving the element of water we should say something about fish; their scaly surface is often fixed in certain colors, sometimes all over, sometimes with stripes, and sometimes with flecks. More frequently it shows a certain iridescence which hints at the relationship between scales and the sheaths of shellfish, mother-of-pearl, even the pearl itself. We must not overlook the fact that warmer climates have an influence even under water and will create, beautify and heighten color in fish.

645. In Tahiti, Forster[68] observed fish with a beautiful play of colors

on their surfaces, especially at the moment they died. Here we may also recall the chameleon and similar phenomena; these things considered together will bring a clearer understanding of them.

646. Lastly, but not as part of this sequence, the iridescence of certain mollusks deserves mention, as does the phosphorescence of several sea creatures said to vanish in an iridescent play of color.

647. We will, of course, find ourselves surrounded by a living realm of color when we turn to creatures belonging to the light, the air, and dry warmth. Here, in finely organized parts, we will see the basic colors at their purest and most beautiful. They tell us, however, that these creatures are still at a lower level of structure because these basic colors can appear in them in an unrefined form. In this case, too, heat appears to contribute in a large way to the development of this effect.

648. We find insects which can be viewed as concentrated dyestuff. Cochineal insects are the most famous of these; we should also mention that the way they settle on plants and even nest in them creates the excrescences used as mordants to fix color.

649. The most striking display of the power of color together with a regular structure occurs in insects which require a complete metamorphosis as part of their development, in beetles and especially in butterflies.

650. The latter might be considered true products of light and air; in their caterpillar stage they already show the most beautiful colors, specific enough to hint at the future colors of the butterfly. If pursued, this observation would surely lead to a satisfying insight into several secrets of structure.

651. When we observe the wings of the butterfly more closely we will discern the rudiments of an extension in its reticulated tissue, and see how this seemingly flattened extension is covered with delicate feathers to become an organ for flight. Here we appear to have found a law governing the great variety of color, one we will discuss later.

652. It is hardly necessary to remind the reader that heat also has a general influence on the size of the creature, the development of its form, and the fuller display of its colors.

LIII. BIRDS

653. The more we approach the higher forms of structure, the more we will need to add brief remarks in passing. Everything such an organic being undergoes in nature is the effect of so many premises that our discussion would be presumptuous and inadequate without some indication of these.

654. In plants we find the higher members, the fully formed flowers and fruits, seemingly rooted on the stem and nourished by more perfect

juices than the root first provides; we also note that the parasitic plants which treat the organic realm as their element are well endowed with powers and qualities. We may also compare the feathers of birds to plants in a certain sense. The feathers emerge as a consummation from the surface of a creature which still has much to give to the external world, and thus they are richly endowed organs.

655. The quills not only grow rather long, but they also branch throughout and thereby become actual feathers. Many of these branches and feathery tufts are further subdivided in a way reminiscent of plants.

656. Feathers are quite different in shape and size, but it is always the same organ which takes on form and changes in accord with the character of the bodily part from which it springs.

657. Color varies with the shape, and a certain law guides coloration in general as well as what we would call particular coloration; i.e., the process which causes the individual feather to be mottled. It is this law which gives rise to all marking with multicolored feathers, and ultimately to the peacock's tail. The law is similar to the one we developed earlier concerning the metamorphosis of plants; we plan to describe it at our earliest opportunity.

658. Although time and circumstance require that we pass by this organic law, it is necessary to mention the chemical effects regularly found in the coloration of feathers, a process already familiar to us.

659. Feathers may be any color, but on the whole yellow feathers which intensify to red are more common than blue feathers.

660. The effect of light on feathers and their colors is quite noticeable. In certain parrots, for example, the breast feathers are actually yellow. There is an intensification from yellow to red in the scalelike tip upon which light falls. Thus the breast of such a creature looks bright red, although blowing into the feathers will make yellow appear.

661. The exposed part of feathers is always quite different from the part protected when the bird is at rest. In ravens, for instance, only the protected part shows iridescent colors, while the exposed part does not. When a collection of tail feathers has been mixed about it is easy to put them back in order by following this rule.

LIV. MAMMALS AND HUMANS

662. Here the basic colors begin to depart entirely. This is the highest stage, and we will discuss it only briefly.

663. In general, mammals stand clearly on the side of life. Everything about them is alive. We will not speak of their inner structure, but we will make a few observations about their surface. Hair differs from feathers since it is more a part of the skin; it is simple, threadlike, not branched. It resembles feathers, however, in being shorter or longer,

thinner or thicker, colorless or colored on different parts of the body. In this it follows laws which may be formulated.

664. White and black, yellow, yellow-red and brown alternate in various ways, but their appearance is never reminiscent of the basic colors. Instead they are all mixed colors subdued by organic coction; they offer some indication of the level attained by the creature in which they are found.

665. In morphology one of the most important findings about surfaces is that even quadrupeds show a relationship between the spots on their skin and the bodily parts beneath them. As capricious as nature may seem to the casual observer, it is nonetheless possible to find the consistent effect of a deep law here. Of course, only careful observation and truly sympathetic interest will allow us to understand how to formulate and apply this law.

666. In the apes we find certain bare parts which appear in bright, basic colors; this shows that such an animal is far from perfection.[69] We may state that the nobler the creature is, the more refined will be the material substance in him; the more essential the connection between his surface and interior, the less likely the presence of basic colors on him. The combination of everything into a perfect whole precludes separation here and there into specific elements.

667. We have little to say of man, for he stands entirely apart from the general principles of nature which concern us here. So much has been furnished for the interior of man that his exterior can be endowed only sparsely.

668. Animals are more burdened than blessed with muscles just beneath the skin; much that is superfluous seeks to come to the surface, like large ears and tails as well as hair, manes, and tufts. When we consider these things we see that nature has much to give, much to lavish.

669. By contrast, the surface of man is smooth and clean; in the most perfect instances it lets us see the beauty of the human form, although there are a few spots more bedecked than covered over by hair. We may remark in passing that an excess of hair on the chest, arms, and thighs indicates weakness rather than strength. Occasional praise for such hairy heroes comes only from poets, who are misled by the characteristic of strength found in animals.

670. Here, however, our principal interest is color. The color of the human skin is never a basic one, but appears as a shade well refined by organic coction.

671. The color of skin and hair is unquestionably connected with differences in character; even blonds and brunets differ significantly. This leads to the conjecture that such a difference arises when a particular organic system predominates. A similar hypothesis might be

applied to nations, and in the process we might note that certain colors also correspond with certain structures, as we can see in the physiognomy[70] of the Moor.

672. In any case, this would be the place to respond to the problematic question of whether every human structure and color might not be equal in beauty, with a preference for a particular one based purely on custom or prejudice. In the light of all we have discussed, however, we venture to say that the most beautiful is the white person, i.e., the person whose surface tends from white to yellow, brownish, or reddish; in short, whose surface appears most neutral and least inclined to some particular quality. In a later discussion of structure we may find a similar culmination of human form. We do not pretend to have resolved this longstanding debate once and for all; there are many who have good cause to doubt the significance of external appearances. We only wish to express a conclusion which consistent exercise of observation and judgment might yield to the soul seeking calm and certain ground. And so let us end with a few comments on the principles of elemental chemical colors.

LV. PHYSICAL AND CHEMICAL EFFECTS OF COLORED ILLUMINATION

673. Since the physical and chemical effects of colorless illumination are well known, it will be unnecessary to discuss them here in detail. Colorless illumination under various conditions will excite warmth, impart a glow to certain objects, or have an effect on oxidation and deoxidation. These effects will vary widely in type and intensity, but not as widely as those found in colored illumination, which we will now describe briefly.

674. We may say the following about the effect of colored illumination in exciting warmth. Let us measure the temperature in a dark room by using a so-called dry-bulb thermometer which is quite sensitive. The liquid will, of course, indicate a much higher temperature if the bulb is put in direct sunlight, and when we place colored glass over it the temperature will naturally fall again since the effect of direct light is somewhat weakened by the glass itself, and especially since the dark quality of the colored glass allows less light to pass.

675. Here, however, the careful observer will note that the excitation of warmth varies with the color of the glass. Yellow and yellow-red glass produces a higher temperature than blue or blue-red; the difference is significant.

676. To do this experiment with the so-called prismatic spectrum we may begin by noting the thermometer reading in the room. When we put the bulb in the blue light the temperature will be somewhat higher,

and this increase will continue as the bulb is passed through the remaining colors. In yellow-red the temperature will be highest; below the yellow-red, however, it will be even higher.

With the water prism arranged so that the center is fully white, the refracted light which is not yet colored will be the warmest; the rest of the colors will behave as indicated.

677. Here we will only indicate these phenomena without discussion or explanation. We merely note in passing that the light does not cut off completely below the red end of the spectrum, for we find a further light refracted, diverted from its path, and apparently creeping in behind the form created by prismatic colors. Thus closer observation makes it unnecessary to have recourse to invisible rays and their refraction.[71]

678. We find the same difference in the way colored illumination imparts light. Light may be imparted to Bologna phosphorus through blue or violet glass, but not through yellow or yellow-red. It is even said that after becoming luminous under violet or blue glass, a phosphorus placed under yellow or red-yellow glass will lose the glow more quickly than when left untouched in a dark room.

679. As before, these experiments may be done with the prismatic spectrum; the results will be the same.

680. We may investigate the effect of colored illumination on oxidation and deoxidation as follows. Let us brush damp, fully white horn silver[72] on a strip of paper, let it turn gray in the light, and cut it into three pieces. We may place one in a book as a standard of reference; the second should be placed under yellow-red glass and the third under blue-red glass. The latter piece will turn a darker gray, indicating deoxidation. The one under yellow-red will become lighter gray and tend to return to its original state of complete oxidation. Comparison with the reference piece will show that both processes have occurred.

681. A way has been found to conduct these experiments conveniently with the form created by the prism. The results are in keeping with the ones mentioned above. We will give the details of these at a later time when we present the work of a painstaking observer who has pursued these experiments with great care.[73]

LVI. CHEMICAL EFFECT IN DIOPTRIC ACHROMATISM

682. We will first ask the reader to review our earlier discussion of this material (§§285–298) so that there will be no need to present it again here.

683. Thus it is possible to lend glass a property of producing much broader color fringes without stronger refraction, i.e., without shifting the form further in any noticeable way.

684. This property is imparted to glass by metal oxides. Minium creates the effect when melted and united thoroughly with clear glass. Flint glass (§291) is such a glass made with lead oxide. Further steps have been taken in this direction: so-called butter of antimony,[74] prepared as a clear liquid by a new process, has been used in vessels shaped like lenses or prisms. It creates a very strong color effect with moderate refraction, and offers a vivid example of what we have called hyperchromatism.

685. We should remember that common glass is largely alkaline in nature, produced mainly by melting sand and alkaline salts together. Hence a series of experiments exploring the relationship of completely alkaline liquids to completely acid ones might be instructive.

686. If the maximum and minimum were found, we might be able to invent some refractive medium in which the increase or decrease of color, almost independent of refraction, could be completely nullified when the form is displaced.

687. For this last point as well as for our entire third section, and even for the theory of color in general, we would hope that those concerned with a progressive, modern study of chemistry might also enter this field, pursue our rough indications in more detail, and work them out in a general way that is consistent with science as a whole.

Part Four
General Observations on the Principles of Color

688. Until now we have almost forcibly kept separate phenomena which constantly sought to satisfy their nature and the needs of our intellect by reuniting. We followed a certain method in our three-part presentation: first we noted color as a fleeting effect and countereffect in the eye; then as a transient effect on light, one produced by translucent, transparent, or opaque bodies without color; and lastly we arrived at the point where we could treat color with confidence as permanent, really a part of objects.

689. In this continual sequence we have sought to define, separate, and organize the phenomena as much as possible. No longer in fear of mixing or confusing these phenomena, we may now show the general principles we can deduce for them in the closed circle of our subject, and then indicate how this circle is connected to other phenomena in nature, how they are linked together.

The Ease with Which the Color Arises

690. We have observed that color arises quickly and easily under a variety of circumstances. The sensitivity of the eye to light, and the

regular reaction of the retina to it, will immediately produce a slight play of colors. Any subdued light can be viewed as colored; it might even be said that all light is colored to the extent it is seen. To some extent, colorless light and colorless surfaces are abstractions; we will scarcely find them in the empirical realm.

691. Colors appear instantly when light touches a colorless object, reflects from it, or passes across or through it. But here we must recall a point we have often urged on the reader: these basic conditions for refraction, reflection, etc., are not enough to produce the phenomenon. Light sometimes produces an effect when acting alone, but more often when defined, bounded, a light-form. Turbidity in the medium is often a necessary precondition, and semishadows and double shadows are needed for several color phenomena. In every case, however, color arises instantly and with the greatest ease. Thus we find color produced immediately by pressure, breath, rotation, warmth—by many kinds of movement and change in smooth, clear bodies or colorless liquids.

692. For color to appear or change in an object, its parts need only the slightest alteration through combination or some other modification.

THE ENERGY OF THE COLOR

693. The physical colors, particularly the prismatic ones, were called *colóres emphatici* in the past because of their special brilliance and energy. Closer examination, however, will show that we may ascribe a strongly emphatic quality to all color phenomena, assuming they are produced under the purest and most perfect conditions.

694. The dark nature of color, its deep, saturated quality, is the source of the serious yet charming impression it creates. We may view color as a modification of light, but it cannot exist in the absence of light, the collaborating force in its appearance, the basis on which it appears, the illuminating power which reveals colors.

THE DETERMINATION OF THE COLOR

695. A color is determined at the same time it is created. Light shows itself and objects in a generally characterless way; it offers us neutral assurance of what is present. Color, however, always appears as specific, full of character and meaning.

696. Considered as a whole, color becomes specific when it belongs to one of two sides. It represents an opposition we may call a polarity; "+" and "−" will serve to designate the poles.

Plus	*Minus*
Yellow	Blue
Causation	Deprivation

Plus	*Minus*
Light	Shadow
Brightness	Darkness
Power	Weakness
Warmth	Cold
Nearness	Distance
Repulsion	Attraction
Affinity to Acids	Affinity to Alkalis

MIXTURE OF THE TWO SIDES

697. The qualities on either side do not cancel one another when the opposites are mixed. If brought to a point of balance where neither side is particularly noticeable, the mixture will acquire a new specific quality for the eye; it will appear as a unity without a trace of combination. We call this unity green.

698. Here, opposite phenomena from the same source do not cancel one another when brought together, but join in a third phenomenon which we note with pleasure, a phenomenon which hints at an accord. A more perfect quality has yet to emerge, however.

INTENSIFICATION TO RED

699. Blue and yellow cannot become more concentrated without giving rise to another phenomenon at the same time. Color (even at its palest) has a dark quality; when concentrated it will become even darker and take on an appearance we may describe as reddish.

700. This appearance will increase until it finally predominates at the highest degree of intensification. A strong impression of light looks purple as it fades. We can scarcely recognize the yellow in the prismatic yellow-red arising directly from yellow.

701. Even colorless turbid media will produce intensification; here we will see the effect in its greatest purity and degree of generality. Clear liquids with a fixed color show intensification quite strikingly in a container with a stepped bottom. This intensification is irresistibly rapid and continuous; it is universal and occurs in physiological colors as well as physical and chemical colors.

UNION OF THE INTENSIFIED EXTREMES

702. The extremes of simple opposites produced a beautiful and pleasant effect when mixed. The intensified extremes will create an even more graceful color when united; indeed, we might expect to find the culmination of the entire phenomenon here.

703. And so it is: there arises the pure red we have often called purple because of its exalted quality.

704. There are various ways for purple to appear: through merger of the violet fringe and the yellow-red border in prismatic color, through continued intensification in chemical color, or through organic opposition in physiological color.

705. It cannot be made as a pigment by mixture or combination, but only by fixing a substance at the highest point of culmination in color. Thus the painter has good reason to postulate three basic colors from which all the rest may be mixed. The physicist, on the other hand, postulates only two basic colors from which the rest may be developed and mixed.

COMPLETENESS IN THE VARIETY OF PHENOMENA

706. The variety of phenomena creates a totality when fixed at its various stages and viewed together. This totality forms a harmony for the eye.

707. We have seen the circle of colors arise before our eyes, and we understand the manifold conditions which produce it. Two pure, primal opposites are the foundation for the whole. Then an intensification occurs by which both approach a third state. Thus on each side there arise degrees: lowest and highest, simplest and most modified, commonest and noblest. We also speak of two combinations (mixtures and unions, as we called them), one a combination of the simple, original opposites and the other of the intensified opposites.

ACCORD WITHIN THE COMPLETE PHENOMENON

708. Seen together, the totality makes a harmonious impression on the eye. Here we must recall the difference between physical contrast and harmonious juxtaposition. The first rests on a pure, unadorned, basic duality viewed as separate; the second on a derived, developed and manifest totality.

709. To be harmonious, a particular juxtaposition must have the quality of totality. Our physiological experiments teach us this. Later we will show how all possible juxtapositions develop around the circle of colors.

THE EASE WITH WHICH COLOR CHANGES FROM ONE SIDE TO THE OTHER

710. We have already had to consider the changeability of color in intensification and traversal of the circle, but colors also move back and forth across the circle, quickly and of necessity.

711. Physiological colors seen against a dark background will be different from those seen against a light one. In physical colors the combination of objective and subjective experiments is noteworthy. It is said that epoptic colors are reversed when seen by transmitted rather than incident illumination. We have shown in detail how chemical colors are changed by fire and alkalis.

THE EASE WITH WHICH COLOR VANISHES

712. We have noted several stages which follow the rapid excitation and determination of color: mixture, intensification, union, separation and complementary harmony. All these occur with the greatest rapidity and promptness, but color is just as quick to vanish entirely.

713. There is no way to arrest physiological effects, and physical effects last only as long as the circumstances which create them. Even chemical effects are extremely changeable, and can be moved back and forth or actually canceled by opposite reagents.

THE PERMANENCE OF COLOR

714. Chemical colors give evidence of long-lasting permanence. Colors fixed by fusion with glass, or by nature in jewels, will defy all effects of time or decay.

715. The technique of dyeing fixes colors quite strongly. Through the use of mordants, pigments otherwise subject to rapid alteration by reagents can become quite permanent on and in objects.

Part Five
Relationship to Other Fields

RELATIONSHIP TO PHILOSOPHY

716. We cannot require a physicist to be a philosopher, but we can expect him to have enough philosophical knowledge to make a fundamental distinction between himself and the world, and then come to terms with the world again in a higher sense. He ought to shape a method consistent with intuitive perception; he must avoid turning the perception into concepts, the concept into words, avoid using and treating these words as if they were objects. He should be familiar with the philosopher's task so that he can pursue phenomena to the borders of the philosophical realm.

717. We cannot ask a philosopher to be a physicist, and yet his in-

fluence on the area of physics is necessary and desirable. Knowledge of every detail is not required, only an insight into the end point where the details converge.

718. Earlier (§§175 ff.) we mentioned this important observation in passing, and we are now at an appropriate place to repeat it. There is no worse mistake in physics or any other science than to treat secondary things as basic and (since basic things cannot be derived from what is secondary) to seek an explanation for the basic things in secondary ones. This gives birth to endless confusion, jargon, and a constant effort to find a way out when the truth begins to emerge and assert itself.

719. Here the observer, the scientific researcher, will be bothered by the fact that the phenomena always contradict his notions. The philosopher, however, can continue to operate with a false conclusion in his own sphere, for no conclusion is so false that it could not somehow be valid as a form without content.

720. But the physicist who can come to an understanding of what we have called an archetypal phenomenon will be on safe ground, and the philosopher with him. The physicist will find safety in the conviction that he has reached the limit of his science, the empirical summit from which he can look back over the various steps in empirical observation, and glance forward into the realm of theory, if not enter it. The philosopher finds safety in accepting from the hand of the physicist results which can serve as his starting point. He will now be justifiably indifferent to phenomena insofar as they are secondary effects organized by science or scattered and disorganized in the empirical state. If he wishes, he may easily examine these phenomena in detail instead of conducting his own research, lingering too long in the intermediate realm, or touching upon the phenomena superficially and without exact knowledge.

721. It has been the author's wish to present the principles of color to the philosopher in this way. For various reasons he may not have succeeded in the discourse itself, but he will pursue this in his revision of the work, in his summary of the discussion, and in the polemic and historical sections. Later, in stating several points more clearly, he will return to this observation.

RELATIONSHIP TO MATHEMATICS

722. Since the physicist deals with the principles of nature as a whole, we can expect him to be a mathematician. In the Middle Ages mathematics was the principal means for seeking mastery over the secrets of nature, and even today geometry properly has an important place in certain areas of natural science.

723. The author cannot boast of any accomplishment in this field,

and therefore restricts himself to those areas which involve no geometry; in recent times such areas have been opened up far and wide.

724. Who would deny that mathematics, one of the most splendid of human gifts, has served physics well in its way? But the false application of the mathematical method has undoubtedly harmed this science as well; here and there we will find this fact grudgingly admitted.

725. The theory of color, in particular, has been hurt and greatly hindered in its progress by being lumped with the area of optics dependent on geometry. It may, in fact, be considered entirely separate from geometry.

726. Another problem arose because a fine mathematician had adopted a completely false concept of the physical origin of color; his great accomplishments as a geometrician long served to sanction his scientific error in a world ruled by constant prejudice.[75]

727. The author of the present work has sought throughout to keep the principles of color apart from mathematics, although at certain points the help of geometry would obviously have been desirable. Had other matters not kept unprejudiced mathematicians of the author's acquaintance from working with him, his discussion would not lack merit in this regard. But this failing might be turned to good advantage if the gifted mathematician will discover where his help is needed in the theory of color, and how he can contribute to the perfection of this branch of science.

728. In general, Germans have achieved much while accepting the achievements of other nations—it would be well if they could also become accustomed to working together. We live, however, in an age altogether opposed to this aspiration. Each wishes to be original in his views and independent of other efforts in his life and work, or at least think that he is. We often find that those who have, in fact, accomplished something quote only themselves, their own writings, journals and compendiums, although it would be much better for them and the world if others were called upon to join in the work. The conduct of our neighbors, the French, is exemplary in this regard, as we may note with pleasure in the instance of Cuvier's preface to his *Tableau élémentaire de l'Histoire naturelle des animaux*.

729. Close observers of the sciences and their progress might even ask whether it is advantageous for such disparate (but related) efforts and goals to be united in one person. Given the limitations of human nature would it not be more appropriate, for example, to make a distinction between those who pursue and discover phenomena, and those who work with them in an applied way? In recent times astronomers who observe the heavens in the search for stars have been somewhat separate from those who calculate orbits, consider the laws of the uni-

verse, and formulate them more precisely. We will return to these points often in the history of the theory of color.

RELATIONSHIP TO THE TECHNOLOGY OF DYEING

730. Our research has given the mathematician wide berth, but we have sought to meet the practical needs of the dyer. Although our section on the chemical aspect of colors is not fully detailed, it and our general observations on color will say far more to the dyer than the earlier theory which offered him nothing at all.

731. Treatises on dyeing are remarkable in this regard. The Catholic may enter his temple, sprinkle himself with holy water, kneel before the priest, and then with no special piety conduct a business discussion with friends or pursue affairs of the heart. Similarly, every treatise on dyeing begins with respectful mention of color theory without any later evidence that something has come of this theory, that this theory has explained or clarified anything, or yielded anything of value for practical application.

732. Those who fully understand the practical needs of dyeing, however, are forced to disagree with the traditional theory, to expose some of its weaknesses and seek a general approach more in keeping with nature and empirical observation. We will say more about this in the historical section when we come to the work of Castel and Gülich.[76] This will also allow us to show how an expanded empiricism comprehending *every accident of nature may actually go beyond its own limits* and be taken up and used as a highly developed whole by the theoretician who is clear-sighted and honest of character.

RELATIONSHIP TO PHYSIOLOGY AND PATHOLOGY

733. Although almost all the phenomena in the section dealing with the physiological and pathological aspects of color are well known, there are some new views which the physiologist will welcome. In particular, we hope to have satisfied him by connecting certain isolated phenomena with similar and like phenomena, thus laying part of the groundwork for his further studies.

734. The pathological supplement is admittedly scanty and disconnected. However, we have outstanding experts who are quite experienced and knowledgeable in this area, and so respected intellectually that they would have little difficulty in revising my discussion, completing what I began, and connecting it with higher levels of insight into organisms.

RELATIONSHIP TO NATURAL HISTORY[77]

735. The author hopes to have done some preliminary work for natural history insofar as we expect this field gradually to become the study of how natural phenomena derive from phenomena of a higher type. Color in all its variety shows on the surface of living beings as a significant outer sign of what is happening within.

736. In one respect, of course, it is not altogether trustworthy because of its uncertainty and changeability, but to the extent it appears as a constant effect, this mutability will itself serve as a criterion for the *mutable qualities of life*. The author could wish for nothing more than to be given the time to develop his observations on this subject, although this is not the place for such a discussion.

RELATIONSHIP TO GENERAL PHYSICS

737. The present state of general physics seems especially favorable for our work; constant and wide-ranging research have brought natural philosophy to such a high level that it now seems possible to relate the endless realm of empirical phenomena to one central method.

738. Without going too far afield, we will find a certain common tendency in the formulas used—if not dogmatically, then at least for didactic purposes as an expression of elementary natural phenomena. This accord in the outward signs must point to an accord in their inner sense.

739. No matter how different their opinions, faithful observers of nature will agree that anything that appears and meets us as phenomenon necessarily implies an original division capable of union or an original unity capable of division, and that the phenomenon must present itself accordingly. To make two of what is one, to unify what is divided—this is the life of nature, the eternal systole and diastole, the eternal syncrisis and diacrisis,[78] the inhaling and exhaling of the world in which we live, weave, and exist.

740. It should be obvious that what we express here through number, through *one* and *two*, must be understood as a higher process, just as the appearance of a third or fourth stage of development is always to be taken in a higher sense. It is especially important, however, that true intuitive perceptions underlie all these expressions.

741. Although we recognize iron as a separate and individual substance, it is neutral, worthy of note only in certain situations and applications. But how little is needed to transform this neutrality! A division takes place; in seeking to reunite and find itself, it develops an almost magical connection to its own kind. This division, in reality a reuniting, spreads throughout its species. Here we recognize the neutral

substance, iron; we see the division arise in it, spread and disappear, only to begin again. In our opinion this is an archetypal phenomenon which borders upon the idea and acknowledges nothing earthly above it.[79]

742. Electricity has its own peculiarities. We know nothing of electricity's essence, for it is neutral. To us it is nothing, a zero, a zero point, a neutral point, but one present in every corporeal substance, a point of origin for a double phenomenon which will emerge at the least provocation and appear only as it disappears again. The conditions under which this appearance occurs are endlessly varied, and depend on the character of the particular bodies involved. From the grossest mechanical friction between altogether different bodies to the subtlest proximity of two similar bodies only slightly unalike in quality, the phenomenon is present and active, even striking and powerful. Its definition and form are such that we properly and naturally apply the formulas of polarity, plus and minus, in the terms north and south, glass and resin.

743. Although this phenomenon takes place especially on the surface, it is by no means superficial. It influences the characteristics of objects, and in its effect it has a direct relationship to the great double phenomenon so prevalent in chemistry, oxidation and deoxidation.

744. It has been our goal to relate the effects of color to this series, this circle, this garland of phenomena, and make a place for it there. Where we have failed, others will succeed. We found a tremendous, primal opposition between light and dark, or to put it more generally, between light and non-light. We sought to mediate this opposition and thus to build the visible world out of light, shadow, and color. As we developed these phenomena we made use of various formulas drawn from the principles of magnetism, electricity, and chemistry. We had to go beyond these principles, however, for we found ourselves in a higher sphere where the relationships requiring expression were more complex.

745. As general forces, electricity and galvanism are superior to magnetic effects, which are more specialized. We may say likewise that color is governed by the same laws, but rises much higher in displaying its qualities to good advantage through its effect on the eye, a noble sensory organ. Compare the various qualities created in the intensification of yellow and blue in red, the union of the two higher extremes in purple, and the mixture of the two lower extremes in green. This system is far more complex than that for magnetism and electricity. There is another reason these latter phenomena are at a lower level: although they permeate and quicken the world as a whole, they are unable to rise to the level of man in a higher sense, for they cannot be

used esthetically. A general, simple, physical system must itself reach a higher level and become more complex if it is to serve loftier purposes.

746. In this sense the reader may recall what we have set forth generally as well as in detail about color; he will then be able to expand and develop for himself the slight indications found here. It would greatly benefit knowledge, science, technology, and art if the beautiful subject of color theory could be freed from its traditional atomistic restraints and isolation, and returned to the general, dynamistic flow of life and activity in which the present age takes such delight. These sentiments will be strengthened when our historical section introduces us to many a brave and insightful man who failed to persuade his contemporaries of his convictions.

RELATIONSHIP TO THE THEORY OF TONE

747. We will proceed to the sensory-moral effects of color, and the esthetic effects arising from them, but this is an appropriate place to say something of their relationship with tone.

It has long been felt that color is related in a certain way to tone; this is shown by the frequent comparisons, some in passing and some in great detail. For the following simple reason, this is an error.

748. Color and tone may in no wise be compared to one another, but both may be related to a higher formula, both may be derived from a higher formula, each in its own way. Color and tone are like two rivers which arise on a single mountain but flow differently through completely opposite regions, so that no two points are comparable as we follow their separate courses. Both are general, basic effects acting in accord with universal law (separation and tendency to union, rising and falling, weight and counterweight), but in quite different directions, in different ways, through different media, on different senses.

749. If some researcher could really take hold of the method we have used in connecting the theory of color with general natural philosophy, and if he could correct our omissions and errors by chance or by insight, we are convinced that the theory of tone could be incorporated fully into general physics; at present its separation is only historical.

750. But herein lies the greatest difficulty: should we destroy the special character of present-day music with its odd practical, accidental, mathematical, esthetic, and creative impulses, could we dissolve it into its basic physical elements and treat it in a purely physical way? This might be possible because of the point we have reached in science and art, and the fine preliminary studies already available.

CONCLUDING OBSERVATION ON LANGUAGE AND TERMINOLOGY

751. We are insufficiently aware that a language is, in fact, merely symbolic, merely figurative, never a direct expression of the objective world, but only a reflection of it. This is especially so when we speak of things which only touch lightly upon our empirical observation, things we might call activities rather than objects. In the realm of natural philosophy such things are in constant motion. They cannot be held fast and yet we must speak of them; hence we look for all sorts of formulas to get at them, at least metaphorically.

752. Metaphysical formulas have great breadth and depth, but a rich content is required to fill them in a worthy way; otherwise they remain empty. Mathematical formulas are often convenient and useful, but they always have a certain stiffness and awkwardness; we soon feel their inadequacy, for even in elementary instances we will quickly recognize the presence of an incommensurable quality. Furthermore, they are intelligible only to a narrow circle of specially trained minds. Mechanical formulas speak more to ordinary understanding, but are themselves ordinary and always retain a touch of crudity. They transform living things into dead ones; they kill the inner life in order to apply an inadequate substitute from without. Corpuscular formulas[80] are similar; they have the effect of rigidifying things in motion, coarsening idea and expression. In contrast, moral formulas express more delicate relationships but take the form of simple metaphors, and may finally lose themselves in a display of wit.

753. However, the scientist might make conscious use of all these modes of thought and expression to convey his views on natural phenomena in a multifold language. If he could avoid becoming one-sided, and give living expression to living thought, it might be possible to communicate much that would be welcome.

754. How difficult it is, though, to refrain from replacing the thing with its sign, to keep the object alive before us instead of killing it with the word. In recent times this danger has been heightened as expressions and terms are drawn from all areas of knowledge and science to express perceptions of simple natural phenomena. We call on the aid of astronomy, cosmology, geology, natural history, even religion and mysticism; and often the particular, the derived, will hide and obscure the general, the elementary, instead of illuminating and revealing it. We are quite aware of the necessity responsible for such a language and its widespread use, and we know that it has made itself indispensable in a certain sense. But this language will be of service only when more moderately and modestly applied in a conscious and sure way.

755. It would be most desirable, however, to base the language for the details of a particular area on the area itself, to treat the simplest

phenomenon as the basic formula and develop the more complex formulas out of it.

756. Scientists have obviously felt that it would be necessary and suitable to use a figurative language in which the basic sign expresses the phenomenon itself, for the formula of polarity has been borrowed from magnetism and extended to electricity, etc. The concepts of *plus* and *minus*, which represent this formula, have found suitable application to many a phenomenon. Even the musician, apparently unconcerned with other fields, has been led by nature to express the principal difference between keys as *major* and *minor*.

757. We, too, have long wished to introduce the term *polarity* into the theory of color, and the present work will show our justification and purpose in doing so. Later we may have an opportunity to link the elementary phenomena of nature in our own way by using this approach, this symbolism always accompanied by the intuitive perception belonging to it. Thus we will be able to clarify and define more adequately the general indications given here.

Part Six
Sensory-Moral Effect of Color

758. Color is ranked high among the primal natural phenomena, for it fills out its own unique sphere in the most various ways. Color is chiefly meant for the sense of vision, the eye; in its most general and basic form, without regard to the character or shape of the surface on which it appears, it acts on man's inner nature through the mediation of the eye. Hence we will not be surprised to find that its effect has a direct connection with the moral realm. A single color acts specifically, while a combination of colors has an effect which is partly harmonious, partly individual, even inharmonious, but always distinct and significant. Thus color, as an element of art, may serve the highest esthetic purposes.

759. People generally take great pleasure in color. The eye needs color as it needs light. We may recall our feeling of refreshment when the sun breaks through the clouds to flood a part of the landscape with light and make its colors visible. The belief that colored jewels have healing powers may be a result of the deep feelings aroused by this inexpressible delight.

760. The colors seen in objects are not entirely external to the eye, are not imprinted on the eye from without. No—the eye itself has a constant predisposition to bring forth colors, and feels pleasure when something in harmony with its own nature comes to it, when its ability to respond is evoked strongly in a certain direction.

761. The idea of opposition between phenomena, and what we now know of particular modifications in this opposition, will lead us to conclude that the impressions made by individual colors are not interchangeable, that they have specific effects and must produce decidedly specific states in the living organ which is the eye.

762. They have a similar effect on man's inner nature. Observation will tell us that each color brings its particular mood. It is told of a witty Frenchman: "Il prétendoit que son ton de conversation avec Madame étoit changé depuis qu'elle avoit changé en cramoisi le meuble de son cabinet qui étoit bleu."[81]

763. To experience these specific, strong effects the eye must be entirely surrounded by one color; e.g., we must be in a room of one color, or look through a colored piece of glass. We will then identify ourselves with the color; our eye and spirit will be brought into unison with it.

764. The colors on the plus side are yellow, red-yellow (orange), and yellow-red (minium, cinnabar). They bring on an active, lively, striving mood.

YELLOW

765. Yellow is the color nearest light. It arises from very slight moderation of light, whether through turbid media or weak reflection from a white surface. In prismatic experiments it extends far into the bright area, where it can be seen in its greatest purity when the two poles are still separate and yellow is not yet mixed with blue to create green. We have already described in detail how the chemical yellow develops in and across the white.

766. In its greatest purity it always conveys the quality of brightness, and has a cheerful, vivacious, mildly exciting character.

767. In this form it makes a pleasant surrounding, whether in clothing, curtains, or wallpaper. Gold in its unalloyed state brings us a new and exalted idea of this color, especially when enhanced by the metal's gleam. Similarly, a strong yellow on lustrous silk (e.g., satin) has a magnificent and noble effect.

768. We also experience a very warm and cozy impression with yellow. Thus in painting, too, it belongs among the luminous and active colors.

769. This warming effect is most vivid when we look at a landscape through a piece of yellow glass, especially on a gray wintery day. The eye is gladdened, the heart expands, the feelings are cheered, an immediate warmth seems to waft toward us.

770. In its pure and bright state this color is pleasurable and cheering, with an element of vivacity and nobility in the force with which it works.

It is extremely delicate, however, and makes a very unpleasant impression when muddied or drawn a little toward the minus side; hence the unpleasant quality in the color of sulfur, which tends toward green.

771. On impure and coarse surfaces, like woolen cloth, felt, etc., where it cannot appear with its full energy, yellow creates an unpleasant effect of this sort. A tiny, imperceptible shift changes the beautiful impression of fire and gold into a muddy one. The color of honor and joy becomes the color of shame, loathing, and disquiet. This may explain the yellow hat of the bankrupt and the yellow circles on the Jew's mantle; even the so-called cuckold's color is actually just a muddy yellow.

RED-YELLOW

772. No color may be considered fixed; it is quite easy to intensify and heighten yellow to a reddish hue by condensing and darkening it. As red-yellow, the color increases in energy and seems to grow in power and magnificence.

773. What was said about yellow will be even more applicable here. Red-yellow brings the eye a strong feeling of warmth and joy, for it represents the intense glow of fire as well as the softer refulgence of the setting sun. Hence it also gives pleasure in our surroundings and is rather joyous or magnificent in clothing. A slight reddish cast immediately lends a different appearance to yellow; as Father Castel[82] has noted, the English and Germans are content with bright pale yellow tones in leather, but the French love yellow intensified to red. In fact, the French generally take pleasure in any color on the active side.

YELLOW-RED

774. Pure yellow passes very easily into red-yellow, and the intensification of the latter to yellow-red is equally inevitable. The pleasant, cheerful feeling created by red-yellow is intensified in deep yellow-red to a feeling of unbearable power.

775. Here the active side displays its highest degree of energy, and it is no wonder that robust, healthy, rough people take special pleasure in this color. A preference for it has frequently been noted in primitive peoples. And when children are left to paint on their own, they make lavish use of cinnabar and minium.

776. If we stare at a uniformly yellow-red surface, the color will actually seem to bore its way into our eye. It produces an incredible shock, and retains its effect even in a degree of darkness.

The sight of a yellow-red cloth upsets and maddens animals. I have also known educated people who could not bear to meet someone wearing a scarlet cloak on a gray day.

777. The colors on the minus side are blue, red-blue, and blue-red. They bring an anxious, tender, longing mood.

BLUE

778. Just as yellow always conveys something of light, we can also say that blue always conveys something of darkness.

779. This color has a strange and almost inexpressible effect on the eye. As color it has its own energy, but on the negative side; in its purest form it is like a stimulating nullity. Its appearance brings an sense of contradiction between stimulation and ease.

780. We see the heights of heaven and the distant mountains as blue. Likewise, a blue surface seems to recede from us.

781. Just as we like to pursue a pleasant object retreating into the distance, we also like to look at blue—not because it attacks us but because it draws us along.

782. Blue brings a feeling of cold and reminds us of shadow. We have already learned how it is derived from black.

783. Rooms decorated only in blue seem rather expansive but quite empty and cold.

784. Blue glass shows objects in a sad light.

785. Blue mixed to some extent with the plus side has an agreeable effect. In fact, sea green is a lovely color.

RED-BLUE

786. We found that yellow intensifies easily, and we will note the same characteristic with blue.

787. Blue intensifies delicately toward the red, thus gaining somewhat in power even though it belongs on the passive side. Its effect, however, is quite different from that of red-yellow. It does not enliven so much as it unsettles.

788. Just as the intensification itself is inexorable, so, too, will we feel a need to make our way through this color—not, as with red-yellow, because we wish to take active strides, but because we seek a resting point.

789. In a very dilute form this color is called lilac; even in this form it has an element of liveliness but lacks gaiety.

BLUE-RED

790. The unsettling effect increases with further intensification, and we can say that wallpaper in a very pure, saturated blue-red would seem unbearable. This is why a very dilute and light form of this color

is used in clothing, ribbons, and other ornamentation; there it has a special charm in keeping with its nature.

791. The higher clergy has taken this uneasy color as its own; we might say that it seeks to climb the unsteady ladder of incessant intensification to achieve the cardinal's purple.

RED

792. Under this heading we must exclude anything which leaves an impression of yellow or blue in red. We may think of a very pure red, a perfect carmine dried on a white porcelain saucer. Because of its exalted nature we have frequently called this color purple, although we know that the purple of the ancients tended more to the blue side.

793. Those familiar with the origin of prismatic purple will find no paradox in the statement that this color contains all other colors, in part manifest, in part latent.

794. With yellow and blue we noted an incessant intensification to red, and we observed our feelings as this took place. It will come as no surprise that a genuine resolution occurs in the union of the intensified poles, a satisfaction in the ideal realm. Among physical colors, then, this most exalted of color phenomena arises from the merger of two opposites which have been gradually prepared for union.

795. As a pigment, however, it seems fixed, and appears in cochineal as the most perfect red. Although it is possible to shift this material chemically to the plus or minus side, we may consider it fully balanced in the best carmine.

796. The effect of this color is as unique as its character. It may make a serious and dignified impression, or one of grace and charm; the first effect arises when it is dark and condensed, the second when light and dilute. Thus the dignity of age and the charm of youth may be clad in a single color.

797. History provides many examples of how rulers have coveted the purple. Surroundings in this color are always serious and magnificent.

798. Purple glass shows a well-lit landscape in an awe-inspiring and terrible light. This must be the color cast over heaven and earth on the day of judgment.

799. The two materials used to produce this color in dyeing, kermes and cochineal, have a certain tendency toward the plus and minus sides; by treating them with acids and alkalis we can shift them back and forth. Thus we will find that the French prefer the active side (e.g., French scarlet), while the Italians remain on the passive side with a scarlet retaining a hint of blue.

800. A similar treatment with alkalis produces crimson, a color apparently despised by the French since they apply the expressions *sot*

en cramoisi and *méchant en cramoisi* to things they find extremely silly or bad.

GREEN

801. We have characterized yellow and blue as the simplest and most basic colors. The color called green arises when yellow and blue are joined where they first appear and create their impression.

802. The eye finds a physical satisfaction in green. When the mixture of the two colors which yield green is so evenly balanced that neither color predominates, the eye and the soul come to rest on the mixture as if it were something simple. We cannot and will not go beyond it. Thus green is often chosen for rooms where we spend all our time.

TOTALITY AND HARMONY

803. For the purposes of discussion we have assumed it is possible to force the eye to identify itself with a single color, but this identification will last but an instant.

804. When a color around us creates its characteristic effect in the eye and forces us by its presence to remain identified with it, we are under a compulsion which the eye will not willingly accept.

805. Upon perceiving a color the eye immediately becomes active; by nature it unconsciously and necessarily produces another color on the spot, and the two colors together will contain the whole circle of colors. The specific sensation aroused by one color will stimulate the eye to seek a totality.

806. To perceive this totality and find satisfaction, the eye looks around each colored space for a colorless one where it can produce the complementary color.

807. Here we find the basic law governing all harmony of colors. The reader may discover this for himself by becoming thoroughly familiar with the experiments described in the section on physiological colors.

808. When presented with the totality of colors in an external object, the eye will rejoice because the result of its own activity stands before it as a reality. Hence we will begin with a discussion of this harmonious juxtaposition.

809. To understand this most easily we may think of the diameter of our color circle as a movable line; when rotated through the entire circle the two ends will eventually indicate all the complementary colors. These, of course, may be reduced to the three simple opposite pairs:

810. Yellow demands red-blue,
Blue demands red-yellow,
Purple demands green,

and vice versa.

811. As we move our imaginary pointer away from the midpoint in this natural order of colors, the other end will also move, but along the opposite series of colors. Such an arrangement will make it possible to find the required complement of every color. We have shown the colors and their transitions as discrete, but for this purpose it would be helpful to construct a color circle with continuous gradations. Here we have arrived at an important point, one deserving our fullest attention.

812. Previously we were affected in a somewhat pathological way when viewing single colors, for we were swept up in specific sensations: we felt lively and active, passive and anxious, lifted to exalted heights, or reduced to the mundane. But the eye's inborn need for totality allows us to escape this limitation; it finds its freedom by creating the opposite of the color forced on it, thus producing a satisfying whole.

813. These truly harmonious opposites are simple but important as evidence that nature is inclined to set us free through totality, for here we are the direct beneficiaries of a natural phenomenon with esthetic implications.

814. Now we can say that our color circle will have a pleasing effect, if only because of the colors it contains. Here we may note that past observers have mistakenly used the rainbow as an example of color totality although a major color—pure red or purple—is missing; this color cannot appear because, as in the usual prismatic image, yellow-red and blue-red cannot merge.

815. In fact, no general phenomenon in nature manifests the totality of colors. We can produce this totality in all its beauty by experiments, but pigments on paper serve best to show how the phenomenon as a whole forms a circle—at least until our natural gifts, a multitude of observations, and much practice imbue us with the idea of this harmony so that it stands before our mind's eye.

COMBINATIONS WITH CHARACTER

816. Besides the purely harmonious, self-generated combinations which always contain a totality, we can identify arbitrary combinations produced along the chords rather than the diameters of our color circle, i.e., so that the color lying between any two other colors is skipped.

817. We say these combinations have character because they possess a distinctive quality: they make a certain impression without satisfying us. Character appears only when the part stands out from the whole, when it is related to the whole without being lost in it.

818. Based on our knowledge of how colors arise and are related

through harmony, we will expect to find a particular impression associated with the character of each arbitrary combination. We will review them one by one.

YELLOW AND BLUE

819. This is the simplest of these combinations. We might say it lacks content, for there is no trace of red and therefore too little of the totality. In this sense we may call it impoverished; it is also mundane since the two poles are at their lowest level. Nonetheless, it has the advantage of being close to green and thus close to a physical satisfaction.

YELLOW AND PURPLE

820. This is rather one-sided, although it has an element of brightness and magnificence. We see the two extremes of the active side together, but without any sense of progressive development.

Since mixing yellow and purple pigments yields yellow-red, they may to some extent represent this color.

BLUE AND PURPLE

821. These are the two extremes of the passive side, but with the upper extreme's tendency toward the active side predominant. Mixing *the two yields blue-red; the combination will resemble blue-red in its* effect.

YELLOW-RED AND BLUE-RED

822. These are the intensified extremes of the two sides and have a somewhat exciting, exalted quality in combination. They hint at the purple created by their merger in prismatic experiments.

823. When mixed, any of these four combinations would produce the color between them on the color circle; combinations composed of small bits of color viewed from afar will also produce this intermediate color. A surface with narrow blue and yellow stripes will look green at a distance.

824. Looking at blue and yellow together, however, will involve the eye in a futile struggle to produce green; i.e., it will never come to rest in one color or reach a sense of totality in the whole.

825. Thus we can say with justification that these combinations have character; the character of each is related to the character of the single colors in the combination.

COMBINATIONS WITHOUT CHARACTER

826. Now we will turn to the last set of combinations. These are easy to find on the circle: they are indicated by the lesser chords formed by passing over the point of transition between each color rather over than an entire intermediate color.

827. We may say that these combinations are without character because they lie too close to one another to make a particular impression. Yet several deserve attention as indicators of a certain progressive development, even though the steps in this development remain almost imperceptible.

828. Thus yellow and yellow-red, yellow-red and purple, blue and blue-red, blue-red and purple, contain successive stages of intensification and culmination. In certain proportions their effect will not be unpleasant.

829. Yellow with green is always mundane but cheerful, while blue with green is always mundane but disagreeable; this is why our forebears called the latter "fool's colors."

RELATIONSHIP OF THE COMBINATIONS TO LIGHT AND DARK

830. We can vary these combinations greatly by using a light shade of each color, or a dark shade, or a light shade of one and a dark shade of the other. In each case, however, the general impression will remain the same. We will mention only the following among the infinite variety of effects possible.

831. With black, the active side becomes more energetic and the passive side less so. With white and bright shades, the active side loses power and the passive side becomes more lively. With black, purple and green look dark and somber; with white, they look more cheerful.

832. A color may also be muddied or rendered somewhat unrecognizable and then combined with its own kind or with pure colors. Although this will create infinite degrees of variety, the principles found with the pure colors remain generally valid.

HISTORICAL OBSERVATIONS

833. We dealt with the principles of color harmony above, but it will be useful to add several observations and examples to that discussion.

834. These principles were derived from man's own nature and the relationships we have recognized in color phenomena. Empirical observation brings us many things in accord with these principles and some things which are not.

835. Aborigines, uncivilized nations, and children favor color at its most energetic, hence yellow-red in particular. They also like brightly variegated colors; i.e., combinations of colors at their most energetic but without harmonic balance. If, however, such a balance is found by instinct or accident, a pleasant effect will result. I recall a Hessian officer back from America who painted his face with pure colors like the Indians, thus producing a totality of sorts which was not unpleasant in its effect.

836. The people of southern Europe dress in very lively colors; the easy availability of silk fabrics favors this tendency. Especially the women with their vivid bodices and ribbons seem always to be in harmony with the landscape, although they cannot outshine the brilliance of the sky and earth.

837. The history of dyeing shows that certain technical considerations and advantages have greatly influenced the costume of various nations. Thus the Germans often wear blue because of its durability in cloth. In many regions the country folk wear green twill because twill takes green well. Any alert traveler will soon observe such things to his amusement and edification.

838. Just as colors create moods, they may also fit moods and situations. Lively nations (the French, for example) love intensified colors, especially those on the active side. More subdued nations (the English or Germans, for example) prefer straw yellow or leather yellow, which they wear with dark blue. Nations which cultivate dignity (like the Italians and Spanish) wear cloaks in a red which tends more to the passive side.

839. In clothing we associate the character of the color with the character of the person. Thus we can observe how single colors and combinations of color are related to complexion, age, and social class.

840. Young women prefer rose and sea-green, older women like violet and dark green. Blonds tend toward violet and light yellow, brunets toward blue and yellow-red; in both cases with good reason.

The Roman emperors were extremely jealous of their purple. The robe of the Chinese emperor is orange embroidered with purple. His servants and members of religious orders are allowed to wear lemon-yellow.

841. Cultivated people tend to shy away from color. This may result partly from weakness of the eye and partly from a lack of certainty in taste which prefers to take refuge in no color at all. In our day women almost always choose white, and men wear black.

842. Here it would not be inappropriate to observe that although people like to be noticed they also like to blend in with their own kind.

843. Black was supposed to remind the Venetian nobleman of republican equality.

844. The extent to which the gray Northern skies have gradually banished colors might be a matter for further research.

845. Absolute colors are naturally quite limited in their use, but muddied, quenched colors (the so-called fashionable colors) create endless varieties of degree and shade, most of which are not without charm.

846. We must also note that ladies wearing absolute colors risk making a rather somber complexion even plainer, and that women who must hold their own in brilliant surroundings generally need to heighten the color of their complexion with cosmetics.

847. Here it would be amusing to apply the above principles to a critique of uniforms, liveries, cockades, and other insignia. In general we might say that these forms of dress or insignia should not consist of harmonious colors. Uniforms ought to have character and dignity; liveries could strike us as common. It would not be hard to find examples both good and bad, since the circle of colors is limited and has been used often enough.

ESTHETIC EFFECT

848. Above we presented the sensory and moral effect of individual colors and color combinations; on that basis we will now develop their esthetic effect for the artist. We will indicate the most essential points of this effect after first discussing the general requirements for pictorial representation, i.e., light and shadow, which bring us directly to the appearance of color.

CHIAROSCURO

849. Chiaroscuro (light-dark) is the term applied to the appearance of physical objects observed solely through the effect of light and shadow.

850. In a narrower sense this term is often applied to a dark area lit by reflection, but here we will use the word in its original and broader sense.

851. It is possible—and necessary—to separate chiaroscuro from any color effect. The artist will more easily resolve the riddle of depiction by thinking of chiaroscuro as independent of color, and becoming thoroughly familiar with it.

852. Chiaroscuro brings out substance as substance, for light and shadow tell us something about density.

853. Here we must consider the highlight, the neutral tint, and the shadow; in connection with the latter we must also consider the shadow

belonging to the object itself, the shadow cast on other objects, and the illuminated shadow (or reflex).

854. The sphere might serve as a natural example on which to base a general understanding of chiaroscuro, but it is inadequate for esthetic purposes. The flowing unity of such a round form creates a nebulous quality. To achieve an artistic effect, surfaces must be brought out so that the sections in shadow and light take on more definition within the whole.

855. The Italians call this *il piazzoso;* in German we could say *das Flächenhafte* [quality of surface]. Thus, although the best example of natural chiaroscuro is the sphere, artistic chiaroscuro would be represented by a polyhedron in which all kinds of lights, half-lights, shadows, and reflexes were seen.

856. A bunch of grapes is considered a good model for artistic composition in chiaroscuro, especially since its shape can produce an excellent grouping; but this subject is suitable only for a master who knows how to find what he can use in it.

857. To understand our basic concept more fully—for it is difficult to grasp even in a polyhedron—we would suggest considering the cube: its three visible sides bring together a clear representation of light, neutral tint, and shadow.

858. But to proceed to a more complex figure in chiaroscuro, we would select an open book as an example offering more diversity.

859. We will find that antique statuary from the classical age is worked quite skillfully to produce such effects. The parts that catch the light are treated simply while the sections in shadow are more broken up so they can receive a variety of reflections—here we may recall the example of the polyhedron.

860. The paintings from Herculaneum and the Aldobrandini Marriage offer examples of this in antique painting.[83]

861. Modern examples are found in single figures by Raphael, and in complete paintings by Correggio and the Flemish School, especially Rubens.

TENDENCY TO COLOR

862. We seldom find pictures done in black and white.[84] A few works by Polidoro[85] offer examples, as do our copperplate engravings and mezzotints. This style has some value insofar as it deals with form and position, but offers little to please the eye for it depends upon forced abstraction.

863. An element of color will assert itself when the artist lets his feelings guide him. The instant black picks up a bit of blue, there will arise a need for yellow to which the artist will instinctively respond. To enliven the whole he will add yellow as he deems best: pure yellow

in the highlights, yellow reddened and muddied to brown in the shadows.

864. All types of camaïeu or monochrome lead ultimately to the introduction of a complementary opposite or some sort of color effect. Thus Polidoro often added a yellow vase or the like to his black and white frescoes.

865. People have always striven instinctively for color in their practice of art. We see every day how amateur artists begin drawing in ink or black crayon on white paper, progress to colored paper, then various crayons, and finally pastels. In our own time we have seen portraits drawn in silverpoint with cheeks touched with red and clothing in color, and even silhouettes with brightly colored uniforms. Paolo Uccello[86] painted colored landscapes with monochrome figures.

866. Even ancient sculpture was unable to resist this urge. The Egyptians painted their bas-reliefs. Statues were given eyes of colored stones. Marble heads and limbs were draped in porphyry garments, and busts were placed on pedestals of calcite in variegated colors. The Jesuits did not miss this opportunity in fashioning their St. Aloysius in Rome,[87] and modern sculpture uses a stain to differentiate flesh from clothing.

POSITION

867. Linear perspective shows the effect of distance through a progressive gradation in the apparent size of objects; aerial perspective likewise lets us see the effect of distance through a gradation in the clarity of objects.

868. Although the eye, by its nature, sees nearby objects more clearly than distant ones, aerial perspective is actually based on the important principle that all transparent media are somewhat turbid.

869. Thus the atmosphere is always more or less turbid. It shows this characteristic especially well in southern regions when the barometric pressure is high, the weather dry, and the sky clear; then we may note a distinct gradation between objects which are not very far from one another.

870. In general this phenomenon is familiar to everyone, but the painter sees the gradation even when the separation is quite small—or at least has the impression that he sees it. In practice he represents it by a progressive gradation in the parts of an object (a completely frontal face, for example). Here lighting requires attention; this has an effect from the side just as position does from foreground to background.

COLORATION

871. In proceeding to the matter of coloring we will assume that the painter is generally acquainted with our theory of color in outline, and

has familiarized himself thoroughly with the sections and principles most pertinent to him. He will then find it easy to deal with the theoretical elements as well as the practical ones as he studies them in nature and applies them to his art.

COLORATION OF PLACEMENT

872. In nature, coloration first appears in connection with position, for aerial perspective depends on the principle of turbid media. We see the sky, distant objects, and even nearby shadows as blue. At the same time, sources of illumination and illuminated objects appear in gradations from yellow to purple. In many cases, a physiological need for color will immediately arise, and an entirely colorless landscape will seem fully colored because these effects act both with and against one another in the eye.

COLORATION OF OBJECTS

873. Local colors are basic and general colors, but defined by the characteristics of an object and its surfaces. This definition can be endlessly varied.

874. Colored silk looks quite different from colored wool. Each type of preparation and weaving produces its own variation. Roughness, smoothness, and sheen play a role.

875. Thus it is prejudicial to good art to say that the painter should ignore the material in garments and merely paint something like abstract folds. Doesn't this deny all characteristic variation? Is the portrait of Leo X any less excellent because velvet, satin, and moreen are depicted together?[88]

876. In products of nature, the colors appear more or less modified, defined, even individualized; this may be observed in stones and plants, as well as bird feathers and animal fur.

877. The painter's art lies mainly in imitating the actual appearance of particular materials, thus eliminating the general and basic element in color phenomena. In doing so, he will find the greatest difficulty lies in the surface of the human body.

878. Flesh is generally on the active side, but a bluish tinge plays into it from the passive side. The color is completely changed from its basic state, neutralized by the high degree of structure in the human organism.[89]

879. After some reflection on what has been said in this theory of color, the skillful artist will find it easier to bring coloration of placement and coloration of objects into harmony; he will be in a position to depict things infinitely beautiful, varied, and true as well.

Characteristic Coloration

880. The juxtaposition of colored objects as well as the coloration of the space around them should conform to the artist's purpose. This requires knowledge of how our feelings are affected by colors, both singly and in combination. Hence the painter should become thoroughly familiar with the general dualism of color[90] and the colors of each individual object; he should also be familiar with what we have said about the qualities of the colors.

881. We can divide characteristic coloration into three categories, which we may call the powerful, the gentle, and the brilliant.

882. The first of these is produced by a predominance of the active side; the second, by a predominance of the passive side; and the third, by a totality, a balanced presentation of the color circle.

883. The powerful effect is produced by yellow, yellow-red, and purple (when the latter is still on the plus side). Very little violet or blue may be used, and even less green. The gentle effect is created by blue, violet, and purple (when shifted to the minus side). Little yellow or yellow-red should be present, but large amounts of green may be used.

884. To achieve these two effects in their purest form we should keep the complementary colors to a minimum, using only what is absolutely required to satisfy our sense for the totality.

Harmonious Coloration

885. The two characteristic qualities noted above may be called harmonious to some extent, but the true effect of harmony arises only when all the colors are brought together in a balanced way.

886. This allows us to create an effect both brilliant and pleasant, but rather general and thus somewhat characterless.

887. This is why most modern painters use coloration lacking in character. They follow only their instinct, and the goal to which it leads them is a totality; they attain their goal with varying degrees of success, thereby losing the character the picture might otherwise have had.

888. But with our earlier principles in mind, we see how we can be confident in choosing a different color mood for every subject. Of course, the application of these principles demands endless modifications which our creative spirit can achieve only when it is permeated by these principles.

Genuine Tone

889. We may wish to continue borrowing the word *tone* (or rather *tonality*) from music and apply it to coloration; now we can make better use of the term than earlier.

890. We would be justified in drawing a comparison between a picture with a powerful effect and a musical work in a major key, or a painting with a gentle effect and a work in a minor key. We might also find other comparisons to describe modifications of these two basic effects.

FALSE TONE

891. Until now, the word *tone* has been used to describe a veil in a single color spread over the whole picture. This is usually done in yellow, since we instinctively try to shift the picture to the powerful side.

892. We will see a painting in this tone if we look at it through yellow glass. It is worthwhile to do this repeatedly, for the experiment shows the exact effect of such a process: a kind of nocturnal illumination, an intensification, but with the plus side darkened and the minus side muddied.

893. This false tone arose instinctively out of uncertainty about how to proceed; it produces uniformity instead of totality.

WEAK COLORATION

894. This very uncertainty led to such broken use of colors in the painting that the painter simply paints out of gray and into gray, treating colors as delicately as possible.

895. The harmonic contrasts in such a painting are often successful, but they lack boldness because the painter is afraid of producing a multicolored effect.

THE MULTICOLORED EFFECT

896. A painting may easily become multicolored if the painter has an uncertain impression and merely paints an empirical juxtaposition of the colors in their full force.

897. On the other hand, a juxtaposition of weak colors, even ugly ones, will not have a particularly striking effect. The painter transfers his uncertainty to the viewer, who can then offer neither praise nor criticism.

898. It is also important to note that a multicolored effect will be created if properly arranged colors are misused in regard to light and shadow.

899. This is all the more likely to happen because light and shadow are prescribed by the drawing—they are a part of it, so to speak—but color is still subject to choice and caprice.

FEAR OF THE THEORETICAL

900. Until now painters have shown a dread of any theoretical consideration of color and the like; they have even exhibited a decided aversion to it. This was not altogether unjustified, for up to now so-called theoretical considerations have been without foundation, ill-defined, and rather empirical. We hope that our efforts may somewhat allay these fears, inspiring the artist to test our principles in a practical way and call them to life.

ULTIMATE GOAL

901. For it is impossible to attain the ultimate goal without an overview of the whole. Let the artist familiarize himself thoroughly with what we have discussed. Given what we have said, it is only the agreement of light and shadow, position, and true and characteristic coloration that will lend the painting the appearance of perfection.

GROUNDS

902. Earlier artists made a practice of painting on a light ground. It consisted of gesso thickly applied to canvas or wood and then smoothed. An outline was drawn and the picture was given a blackish or brownish wash. We still have pictures prepared in this way for the addition of color by Leonardo da Vinci, Fra Bartolommeo, and also several by Guido.[91]

903. When the artist was adding color and needed to depict white clothing, he sometimes left this ground untouched. Titian did this in his later years, when he was quite sure of himself and knew how to accomplish much with little effort. The whitish ground was treated as a middle shade; then the shadows were added and the highlights brushed on.

904. Even after color was added, the underlying picture (washed on, as it were) continued to have an effect. A garment, for instance, was painted in a transparent color so that the white shone through and enlivened the color, while the section prepared for shadow muted the color without contaminating or muddying it.

905. This method had many advantages. The lighter parts of the picture had a light ground; and the shaded parts, a dark ground. The entire picture was already prepared; the artist could paint with thin colors, certain that the light and the colors would be in agreement. In our time, water color painting is based on these principles.

906. In any case, modern oil painting always uses a light ground.

Middle shades are more or less transparent and therefore enlivened by a light ground; even the shadows are less apt to become dark.

907. Dark grounds were also used for a time; apparently Tintoretto introduced these. It is not known whether Giorgione used them, but Titian's best pictures were not painted on a dark ground.[92]

908. Such a ground was reddish brown, and when the picture was sketched on it the darkest shadows were laid on. The light colors were heavily impasted on the brighter sections, and thinned out toward the shadows; the dark ground then shone through the thinner color as a middle shade. The final effect was achieved by painting over the light sections several times and further adding highlights.

909. Although this method helps speed the work, its results are not beneficial. The energetic ground becomes darker and more prominent; as the light colors lose their clarity, the shadow side grows more overpowering. The middle shades turn darker and darker, and the shadows finally become quite black. Only the thickly applied highlights remain bright, and these bright spots are all that remains to be seen in the picture. The paintings of the school of Bologna and of Caravaggio[93] offer many examples of this.

910. Perhaps it would be well to conclude by mentioning painting with glazes. In such painting the previously applied color is considered a light ground. This method can yield an impression of color mixture, intensification, or so-called tone, but the colors darken in the process.

PIGMENTS

911. We receive these from the hand of the chemist and the scientist. Much has already been said and published about this subject, but it deserves to be reconsidered from time to time. Meanwhile, the master passes his knowledge of it down to the student, and one artist shares it with another.

912. The longest-lasting pigments are preferable, but the way they are used also has a great effect on the longevity of the picture. Thus the fewest possible coloring materials should be used, and the simplest method of application is highly recommended.

913. The large number of pigments has led to many harmful results in coloration. Each pigment has its own way of affecting the eye, and also its own peculiarities in regard to technical application. The former explains why it is harder to achieve harmony with many pigments than with few; and the latter, why chemical reactions occur among coloring materials.

914. Let us recall some other false paths which may seduce the artist. Painters are always looking for new coloring materials, and believe it

represents progress in art when they find them. They also long to master the mechanical techniques of earlier periods, thus wasting much time; e.g., our lengthy and laborious efforts to learn wax painting[94] at the end of the last century. Others set out to invent new techniques, which also accomplishes nothing. It is, after all, only the spirit which brings life to any technique.

ALLEGORICAL, SYMBOLIC, MYSTICAL USE OF COLOR

915. We have shown in detail that each color makes its own impression on the human being, thereby revealing its nature to the eye as well as to the spirit. It follows that color may be used for certain sensory, moral, and esthetic purposes.

916. When this use is completely consistent with nature, we may call it symbolic; the color's function would correspond with its effect, and its true quality would give direct expression to the intended meaning. For instance, the use of purple to represent majesty no doubt represents the right form of expression (as noted earlier).

917. Closely related is another use which could be called allegorical. This is more fortuitous and capricious; we might even say conventional, for the significance of the emblem must be learned before its meaning is clear. This is the case, for instance, with green, which has been assigned the meaning of hope.

918. We can also sense that color is open to mystical interpretation.[95] The scheme depicting the multiplicity of colors points to archetypal relationships which are as much a part of human intuitive perception as they are of nature. These associations could no doubt be used as a language to express archetypal relationships which are not so powerful and diverse in their effect on us. The mathematician values the worth and utility of the triangle, but the mystic venerates it. Much may be schematized in the triangle, and in the phenomena of color as well, for by pairing and converging we may derive the ancient and mystical hexagram.[96]

919. We must grasp how yellow and blue diverge, and should reflect especially on the intensification in red where the opposites incline to one another and merge to create a third element. Then we will certainly arrive at the mystical and intuitive perception that a spiritual meaning can be found in these two separate and opposite entities. When we see them bring forth green below and red above, it will be hard to resist the thought that the green is connected with the earthly creation of the Elohim,[97] and the red with their heavenly creation.

920. But we had best not expose ourselves to suspicions of fantastic imaginings at the end; all the more so since a favorable reception of

our color theory will enable allegorical, symbolic, and mystical applications and interpretations to emerge in keeping with the spirit of our age.[98]

Concluding Observation

Although this work has long occupied me, I am now in a position of publishing it in rather sketchy form—on the spur of the moment, so to speak. As I leaf through these printed pages I recall that a meticulous author once wished that he might have a chance to see the first draft of his works in print; thus he could take a fresh look at them, since every shortcoming stands out more in print than in even the clearest manuscript.

This wish was all the stronger in me because I never had the chance to review my work in a completely clean draft; the successive revisions of these pages came at a time which made it impossible to work in a quiet frame of mind.[99]

I still have much to say to the reader, although part of this may be found in the Introduction. I will be able to say more of my efforts and their fate in the historical section.

Here, however, at least one observation is perhaps not uncalled for: a reply to the question of what can be accomplished in the sciences by someone who cannot devote his entire life to them. A guest in the home of another, how can he help the owner?

If we think of art in the higher sense, we might wish that only masters would practice it, that its students would receive the strictest preparation, and that amateurs would joyfully approach it in a mood of reverence. For the work of art should spring from the creative spirit; the artist should call forth content and form from the depths of his own being, and rule his material in a sovereign way; outer influences should give him only what he needs to accomplish his goal.

But the artist has good reason to honor the dilettante, and this is even truer in scientific matters, where the amateur is in a position to produce something both pleasing and useful. Science is far more dependent on empirical observation than art, and many people are skilled at such observations. Scientific work is collected from many quarters, and needs many hands and heads. Knowledge can be passed on, these treasures can be inherited, and what is accomplished by one will be used by many. Thus none are forbidden to offer what they can to the sciences. We owe much to accident, practical experience, or the observation of a moment. All sorts of people gifted with good sensory skills—women, children—can offer lively and well-placed observations.

Thus science cannot ask those wishing to do something scientific to

devote their entire lives to it and learn all there is to know (quite a bit to ask even of the initiated). If we look through the history of the sciences, especially the natural sciences, we will find many accomplishments made by individuals working in some single field, and often by laymen.

Wherever inclination, chance, or opportunity may lead a person, whichever phenomena strike him, engage him, arrest him, occupy him—the results will always serve to advance science. For every new relationship that is discovered, every new technique—even the imperfect, even error itself—will prove useful and stimulating; it will not be wasted.

In this sense, then, the author can take some comfort when he looks back on his work, and this observation may give him the courage to do what remains to be done. Not satisfied, but consoled, he commends his past and future accomplishments to the interest of the world and generations to come.

Multi pertransibunt et augebitur scientia.[100]

Theory of Tone[1]
[A Schematic Fragment]

The theory of tone develops the laws of what is audible; this arises through the vibration of physical bodies, for us principally through the vibration of the air. In a broad sense there are no bounds to what is audible, but we will set aside *noise, sound* and *speech* within it. Our primary subject will be what is *audible as music* (tone). This arises from the purity and size of the material in the body which vibrates or is vibrated.

To arrive at some measure of this we will first consider the sounding body as a whole. The particular tone produced by the whole we will call a fundamental. When reduced in size, the whole will produce a higher tone, when increased, a lower tone. We may continuously decrease the size; no relations will arise from this. We may divide the whole; this yields relations.

The principal relations lie at some distance from one another (chords). Intermediate relations fill the space between them to create a type of continuity (scale). The tone progresses up and down in steps, until it returns to itself (octave).

This is all that is needed at first; the rest must be developed, modified, and explained in the discussion.

The entire theory is based on empirical observation and presented in three parts.

What is audible as music appears as: I *organic* (subjective), II *mechanical* (mixed) III *mathematical* (objective). All three reconverge, easily through the power of the artist, less so in scientific presentation.

I. *Organic* (Subjective)

As it comes from man himself, and through him, the world of tone brings about a *sensory-moral inspiration of the inner and outer senses.*

1. EMERGING IN THE VOICE

Principles of Song

Song is fully productive in and of itself; natural disposition of the outer senses and creativity of the inner senses are an absolute requirement.

Chest Voice

From the lowest to the highest the voices are: *bass, tenor, alto, soprano.*

Every voice is to be considered as a whole; each contains an octave and a bit more. They overlap and form about three octaves altogether.

They are distributed between the sexes. Thus the importance of *puberty* and the *change* this brings which can be prevented by *castration.*

Register

i.e., the limit of the chest voice.

Head Voice

Transition to the mechanical. The two worked into one.
Structural detail of the chest and throat.
More on the voices of animals, especially birds.

2. RETURNING THROUGH THE EAR

Acoustics

Sensitivity of the ear; its apparent passivity and adiaphorism.[2]

Hearing is a mute sense, only a partial sense, in comparison to the eye.[3] But the ear has an advanced organic nature and we must credit it with *counteracting* and *asserting its own demands,* which alone make the sense capable of taking in and grasping what is brought from without. In the ear, however, we must make special note of the passage inward, for it has a thoroughly activating and productive effect. Through it the productivity of the voice is awakened, stimulated, intensified and multiplied; the entire body is stimulated.

3. AROUSAL OF ACCOMPANIMENT BY THE ENTIRE BODY

Rhythmics

The entire body is roused to walk (march) or leap (dance and gesture).

All organic movements manifest themselves through diastoles and systoles;[4] it is one thing to raise the foot, another to put it down. Here we find weight and counterweight in rhythmics: arsis, upbeat; thesis, downbeat; types of beats (equal, unequal).

These movements may be considered by themselves, but they quickly and necessarily lead to modulation.

II. *Mechanical* (Mixed)

Regular tone produced by various means.

INSTRUMENTS

Their timbre, purity, elasticity.

Material: natural, organic, artificial, metal, wood, glass.

Form: tubes, lengths, surfaces.

Type of vibration: blowing, stroking (crosswise, lengthwise), striking.

Relation to mathematics: Instruments result from insight into relations of size and number, and enrich this insight through their diversity.—Discovery of natural relationships other than through the monochord.—Relation to the human voice: They are a surrogate for this; they stand below it, but may equal it when used sensitively and intelligently.

III. *Mathematical* (Objective)

Use of the simplest external bodies to represent the basic elements of tone and reduce them to relations of number and size.

Monochord: sounding together of harmonic tones; different concepts of how this happens: sympathetic resonance; mechanical resonance, organic necessity and subjective excitation of resonance. Objective proof in reverse through the resonance in the relations of tuned strings.

Basis for the simplest tonal relations; diatonic scale. A requirement in nature not satisfied in this way; what is given empirically impossible to support or represent in this way.

Indication about the minor tone. It does not arise from the basic resonance; it manifests itself in less concrete relationships of number and size, and yet it altogether suits human nature, even more so than the basic, concrete type of tone.

Objective proof in reverse through the resonance in strings tuned to this tone which is taken from empirical observation. (Thus the tonic C gives the harmony of C major above it and F minor below it.)

Major and minor keys as the polarity in the theory of tone. The basic principle of both: the major key created by climbing, by an acceleration upward, by an upward extension of all intervals; the minor key by falling, by an acceleration downward. (The minor scale extended upwards would have to become a major scale).

Development of this contrast as the basis for all music.

(Origin and necessity of the subtonic mode in rising, and the minor third in falling.) Combination of the two modes through dominants and tonics.—(The first must always be major; question whether the second must always be minor.)

Origin of arsis and thesis,[5] and thereby of all movement, thus also of bodily participation and rhythmics.

ARTISTIC TREATMENT

Restrictions of octaves. Their identical joining together.

Definition of tonal relations in accord with nature and against it.

Rounding and softening of tones to allow several types of tones to coexist and be treated alike.

Vocal training. Appropriate practice of what is easier and more difficult, of what is fundamental and secondary.

Contribution of creativity, talent, and the use of all the above as material and tools.

General connection of song with speech, especially in cantus firmus, recitative, and *quasi parlando*.[6]

Difference from speech through a type of register, and

transition to it and thus to $\left\{ \begin{array}{l} \text{practical understanding.} \\ \text{reason.} \end{array} \right.$

$\left. \begin{array}{l} \text{Sound} \\ \text{Noise} \end{array} \right\}$ transition to a random, formless state.

VIII. Selections from *Maxims and Reflections*

Whoever wishes to deny nature as an organ of the divine must begin by denying all revelation.

"Nature conceals God!"[1] But not from everyone!

Archetypal phenomena: ideal, real, symbolic, identical.

Empirical realm: endless proliferation of these, thus hope of succor, despair of perfection.

Archetypal phenomenon:

> ideal as the ultimate we can know,
> real as what we know,
> symbolic, because it includes all instances,
> identical with all instances.

The direct experience of archetypal phenomena creates a kind of anxiety in us, for we feel inadequate. We enjoy these phenomena only when they are brought to life through their eternal interplay in the empirical.

When archetypal phenomena stand unveiled before our senses we become nervous, even anxious. Sensory man seeks salvation in astonishment, but soon that busy matchmaker, Understanding, arrives with her efforts to marry the highest to the lowliest.

The magnet[2] is an archetypal phenomenon; this is clear the instant we say it. Thus it also comes to symbolize all else for which no words or names must be sought.

Basic characteristic of an individual organism: to divide, to unite, to merge into the universal, to abide in the particular, to transform itself,

to define itself, and; as living things tend to appear under a thousand conditions, to arise and vanish, to solidify and melt, to freeze and flow, to expand and contract. Since these effects occur together, any or all may occur at the same moment. Genesis and decay, creation and destruction, birth and death, joy and pain, all are interwoven with equal effect and weight; thus even the most isolated event always presents itself as an image and metaphor for the most universal.

It is not easy for us to grasp the vast, the supercolossal, in nature; we have lenses to magnify tiny objects but none to make things smaller. And even for the magnifying glass we need eyes like Carus and Nees[3] to profit intellectually from its use.

However, since nature is always the same, whether found in the vast or the small, and every piece of turbid glass produces the same blue as the whole of the atmosphere covering the globe,[4] I think it right to seek out prototypal examples and assemble them before me. Here, then, the enormous is not reduced; it is present within the small, and remains as far beyond our grasp as it was when it dwelt in the infinite.

The most sublime metamorphosis in the inorganic realm occurs when the amorphous takes on structure as it comes into being. Every material has the inclination and right to do this. Micaceous schist turns into garnets, often forming minerals with almost no mica; it is found only between the crystals of garnet as a minor formative element of the whole.

The nature with which *we* must work is no longer nature—it is an entity quite different from that dealt with by the Greeks.

The history of science is a great fugue in which the voices of nations are heard one after the other.

Four epochs of science:

childlike,

poetic, superstitious;

empirical,

searching, curious;

dogmatic,

didactic, pedantic;

ideal,

methodical, mystical.

Sciences destroy themselves in two ways: by the breadth they reach and by the depth they plumb.

A crisis must necessarily arise when a field of knowledge matures enough to become a science, for those who focus on details and treat them as separate will be set against those who have their eye on the universal and try to fit the particular into it. Now, however, an ideal, more comprehensive scientific approach is attracting an ever wider circle of friends, patrons, and colleagues; at this higher stage the division is no longer so marked, although still noticeable enough.

Those I would call *universalists* hold firm to the conviction that everything is present everywhere and may be discovered there, although in forms endlessly divergent and varied. The others, whom I will call *singularists,* agree with this principle, and even follow it in their observations, definitions, and teachings. But they claim to find exceptions wherever the prototype is not fully expressed, and rightly so. Their only error lies in failing to recognize the basic form where it is disguised, and denying it where it is hidden. Yet both ways of thought are authentic. They stand in eternal opposition with no prospect of joining forces or defeating one another: hence we must avoid engaging in controversy and simply state our convictions clearly and openly.

I will therefore restate mine: at this higher level we cannot *know,* but must *act,* just as we need little knowledge but much skill in a game. Nature has given us the chess board; we cannot and should not work beyond its limits. She has carved our pieces; gradually we will learn their value, their moves, and their powers. Now it will be our task to find the moves we think best; each seeks this in his own way regardless of any advice. Leave well enough alone, then. Let us merely observe the distance between us and the others, finding our allies in those who declare themselves on our side. We should also recall that we are dealing with an insoluble problem. We must be ready to attend to anything we may hear, especially anything opposed to our own view, for here we will recognize the problematic character of things and, especially, of people. I am not sure I will continue my work in this well-tilled field, but I reserve my right to note and point out certain new directions of study or individual research.

We may use Lichtenberg's[5] writings as a wonderful divining rod: wherever he jests, a problem lies hidden.

He set one of his witticisms in the vast empty space between Mars and Jupiter. Kant had carefully demonstrated that all matter in this area must have been swept up by the two planets.[6] Here Lichtenberg says in his humorous way: "Why should there not be unseen worlds as well?" And wasn't his comment absolutely true? Aren't the newly discovered planets invisible to everyone in the world except a few astronomers whose word we must trust?

Content without method leads to fantasy; method without content to empty sophistry; matter without form to unwieldly erudition, form without matter to hollow speculation.

The worthiest professor of physics would be one who could show the inadequacy of his text and diagrams in comparison to nature and the higher demands of the mind.

Germans—and they are not alone in this—have the knack of making the sciences unapproachable.

Those books which bring us the truths and falsehoods of the day in encyclopedic form have a special role in perpetuating error. There is no application of scientific method here; our knowledge, our beliefs, our assumptions—all are included. This is why after fifty years such works look strange indeed.

In general the sciences put some distance between themselves and life, and make their way back to it only by a roundabout path.

To be popularized, theoretical things must be presented in an absurd manner: the theoretical matter must be shown in practical application before the world at large will accept it.

A scientific researcher must always think of himself as a member of a jury. His only concern should be the adequacy of the evidence and the clarity of the proofs which support it. Guided by this, he will form

his opinion and cast his vote without regard for whether he shares the author's view.

In doing this he should be unconcerned with the question of whether he is in the majority or the minority—he has accomplished his task, he has expressed his convictions, and he cannot command the minds or feelings of others.

The history of philosophy, science, and religion all show that opinions may be circulated en masse, but the one which predominates is the one which is most concrete, i.e., comfortably tailored to the human mind at its most ordinary. In fact, anyone who learns to think in the higher sense may assume that he will find the majority opposed to him.

The ultimate goal would be: to grasp that everything in the realm of fact is already theory. The blue of the sky shows us the basic law of chromatics.[7] Let us not seek for something behind the phenomena—they themselves are the theory.

Weak minds make the mental error of leaping straight from the particular to the general when, in fact, the general is to be found only within the whole.

Nature will reveal nothing under torture; its frank answer to an honest question is "Yes! Yes!—No! No!" More than this comes of evil.[8]

He who beholds a phenomenon will often extend his thinking beyond it; he who merely hears about the phenomenon will not be moved to think at all.

There is a delicate empiricism which makes itself utterly identical with the object, thereby becoming true theory. But this enhancement of our mental powers belongs to a highly evolved age.

The manifestation of a phenomenon is not detached from the observer—it is caught up and entangled in his individuality.

In observing nature on a scale large or small, I have always asked: Who speaks here, the object or you? I also take this approach in regard to my predecessors and colleagues.

There is a secret element of regularity in the object which corresponds to a secret element of regularity in the subject.

. . . Thus when making observations it is best to be fully conscious of objects, and when thinking to be fully aware of ourselves.

When we try to recognize the idea inherent in a phenomenon we are confused by the fact that it frequently—even normally—contradicts our senses.

The Copernican system is based on an idea which was hard to grasp; even now it contradicts our senses every day. We merely echo something we neither see nor understand.

The metamorphosis of plants contradicts our senses in this way.

Reason is applied to what is developing, practical understanding to what is developed. The former does not ask, What is the purpose? and the latter does not ask, What is the source? Reason takes pleasure in development; practical understanding tries to hold things fast so that it can use them.

Thinking man has a strange trait: when faced with an unsolved problem he likes to concoct a fantastic mental image, one he can never escape even when the problem is solved and the truth revealed.

Throughout the history of scientific investigation we find observers leaping too quickly from phenomenon to theory; hence they fall short of the mark and become theoretical.

The Greeks spoke of neither cause nor effect in their descriptions and stories—instead, they presented the phenomenon as it was.

In their science, too, they did not perform experiments, but relied on experiences as they occurred.

The animal is instructed by his sensory organs; man instructs his organs and governs them.

The present age has a bad habit of being abstruse in the sciences. We remove ourselves from common sense without opening up a higher one; we become transcendent, fantastic, fearful of intuitive perception in the real world, and when we wish to enter the practical realm, or need to, we suddenly turn atomistic and mechanical.

Our most basic and necessary concept—that of *cause* and *effect*—leads to numerous and repeated errors in application.

We can grasp immediate causes and thus find them easiest to understand; this is why we like to think mechanistically about things which really are of a higher order.

. . . Thus mechanistic modes of explanation become the order of the day when we ignore problems which can only be explained dynamistically.

A careful review of physics will show that not all the phenomena it studies are of equal value, nor are all the experiments on which it relies.

Primary, archetypal experiments are pivotal, and work based on them has a sure and firm foundation. But there are also secondary experiments, tertiary experiments, etc.; when we give them equal weight we only confuse what was clarified through the primary experiment.

Someday someone will write a pathology of experimental physics and bring to light all those swindles which subvert our reason, beguile our judgment and, what is worse, stand in the way of any practical progress. The phenomena must be freed once and for all from their grim torture chamber of empiricism, mechanism, and dogmatism; they must be brought before the jury of man's common sense.

Few people have the gift of grasping nature and using it directly; between knowledge and application they prefer to invent a phantom which they develop in great detail; doing so, they forget both object and purpose.

The mathematician relies on the element of quantity, on all that is defined by number and size, and thus to some degree on the universe

in its external form. But if we set out to apply the full measure of mind and all its powers to this universe, we will realize that *quantity* and *quality* must be viewed as two poles of material existence. This is why the mathematician refines his language of formula so highly; as far as possible he wants to incorporate the incalculable world into the realm of measure and number. Everything will then seem graspable, comprehensible, and mechanical, and he may be accused of an underlying atheism for supposedly he has included the most incalculable element of all (which we call God), and thus has eliminated its special, overriding presence.

An important task: to banish mathematical-philosophical theories from those areas of physics where they impede rather than advance knowledge, those areas where a one-sided development in modern scientific education has made such perverse use of them.

A strict separation must be maintained between physics and mathematics. Physics must remain quite independent; it must use all its powers of love, respect, and reverence to find its way into nature and the sacred life of nature irrespective of what mathematics does. The latter, on the other hand, must declare itself independent of all externalities, take its own path of intellect, and develop in a purer way than it now does in working with the physical world to gain something from it or impose something on it.

Like dialectics, mathematics is an organ for a higher kind of inner sense; in practice it is an art like rhetoric. Both value nothing but form—the content is unimportant. It does not matter whether mathematics counts pennies or guineas, whether rhetoric defends what is true or what is false.

Here, however, the character of the person doing these things, practicing these arts, is most important. An effective advocate with a just cause, an able mathematician before the starry heavens—both seem equally godlike.

What except for its exactitude is exact about mathematics? And this exactitude—does it not flow from an inner feeling for the truth?

Mathematics cannot eliminate prejudice, prevent willfulness, or resolve partisan differences. It has no power over anything in the moral realm.

A mathematician is perfect only to the degree that he is a perfect human being, to the degree that he can experience the beauty in what is true. Only then will his work be complete, transparent, comprehensive, pure, clear, graceful—even elegant. All this is needed to become a Lagrange.[9]

To escape the endless profusion, fragmentation, and complication of modern science and recover the element of simplicity, we must always ask ourselves: What approach would Plato have taken to a nature which is both simple in essence and manifold in appearance?

Insofar as he makes use of his healthy senses, man himself is the best and most exact scientific instrument possible. The greatest misfortune of modern physics is that its experiments have been set apart from man, as it were; physics refuses to recognize nature in anything not shown by artificial instruments, and even uses this as a measure of its accomplishments.

The Newtonian experiment which forms the basis for the traditional theory of color is extremely complicated; it requires the following:

For the spectral colors to appear we need:

1. a glass prism
2. which has three sides
3. and is small;
4. a window shutter
5. with an opening
6. which is quite small;
7. the sun's form entering
8. and falling on the prism at a certain distance
9. from a certain angle;
10. an image formed on a surface
11. placed a certain distance behind the prism.

If conditions 3, 6, and 11 are not met, if we enlarge the opening, use a large prism, or bring the surface closer, the desired spectrum can and will not appear.

The battle with Newton is actually being conducted at a very low level. It is directed against a phenomenon which was poorly observed, poorly developed, poorly applied, and poorly explained in theory. He stands accused of sloppiness in his earlier experiments, prejudice in

his later ones, haste in forming theories, obstinacy in defending them, and generally of a half-unconscious, half-conscious dishonesty.

In New York there are ninety different Christian sects, each acknowledging God and our Lord in its own way without interference. In scientific research—indeed, in any kind of research—we need to reach this goal; for how can it be that everyone demands open-mindedness while denying others their own way of thinking and expressing themselves?